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SYNOPSIS OF BACKGROUND MATERIAL FOR MIL-STD-210B, CLIMATIC EXTREMES FOR MILITARY EQUIPMENT

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13. ABSTRACT The Design Climatology Branch of the Air Force Cambridge Research Laboratories had the scientific responsibility for leading a DoD Task Group effort to revise MIL-STD-210A "Climatic Extremes for Military Equipment." This new standard, first published in 1953 and updated as MIL-STD-210A in 1957, provides climatic extremes for which worldwide usage of military equipment should be designed. Because the extremes in earlier versions were not specifically expressed as design goals, equipment adopted by one Service for worldwide use was frequently unacceptable for use by the other Services. This created a need to change the specified intent of MIL-STD-210A. In addition, MIL-STD-210A was also in drastical need of revision because of a maturing of concepts in the application of climatic information to equipment design, a vastly improved climatological data base for weather elements currently in MIL-STD-210A, new elements desired by engineers, and the availability of new statistical techniques to process such climatic data.

Accordingly a tri-Service study group was established in 1967 to first determine the need for a revised MIL-STD-210A, and then to prepare the revised document, MIL-STD-210B. Each of the three Services was delegated responsibility to prepare background studies for the revision of extremes for current elements and/or the establishment of extremes for new elements, within a common design philosophy framework established by the study group.

This document represents the fruition of the goals of the task group. It relates the background studies supporting the values in MIL-STD-210B, so that MIL-STD-210B users need to consult only this single document for an elaboration on the MIL-STD-210B extremes. In addition, the report contains information on the origin, necessity for and the events leading to a revision of MIL-STD-210A. Discussions of the major changes in the Standard's philosophy and its contents are also provided.

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14. KEY WORDS	LINK A		LINK B		LINK C	
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Design criteria						
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Temperature extremes						
Humidity extremes						
Wind extremes						
Rain extremes						
Instantaneous rainfall rate extremes						
Blowing snow extremes						
Snowload extremes						
Ice accretion extremes						
Hail extremes						
Pressure extremes						
Ocean temperature extremes						
Density extremes						
Ozone extremes						
Climatic extremes aloft						
Salinity extremes						
Sand extremes						
Dust extremes						
Wind shear extremes						
Land climatic environment						
Naval climatic environment						
XUV Radiation extremes						

Preface

This document was prepared to support values in Military Standard 210B, Climatic Extremes for Military Equipment. The preparing activity (PA) responsibility of this Standard, established in the Army in 1947, was transferred to the Air Force's aeronautical facilities at Wright-Patterson AFB shortly after initial publication in 1953. It has since been assigned to the Air Force's Electronics Systems Division (ESD) at L. G. Hanscom Field, Bedford, Massachusetts with the co-located Design Climatology Branch of the Air Force Cambridge Research Laboratories responsible for the scientific expertise of devising, maintaining, and/or revising the Standard.

The decision to revise MIL-STD-210A was reached through a series of tri-Service meetings initiated in 1967 by the Design Climatology Branch, in response to a memorandum from the Office of the Assistant Secretary of Defense which established a tri-Service task group to make recommendations concerning MIL-STD-210A. Each Service was invited to send three types of representatives to these meetings: a staff official (s) with knowledge of his service's overall environmental goals and calculated risk design philosophy, a systems oriented staff engineer(s) with a background in the application of environmental standards to design (and testing) problems, and an environmental scientist(s) with a background in the presentation of environmental "inputs" for military design criteria. A listing of members of this task group follows:

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Chairman
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Notes:

* Meeting Dates:
1. 24-25 July 1967
2. 7-8 January 1969
3. 17-18 June 1969
4. 13-14 October 1969
5. 17-19 July 1972

** Indicates Department point of contact for MIL-STD-210

Scientific studies to support values of extremes appearing in MIL-STD-210B were prepared by the three Services, with each Service holding prime responsibility for the environment under its general cognizance (that is, land, Army; sea, Navy; air, Air Force). Credit to individuals and organizations providing these studies follows:

CONTRIBUTORS OF SCIENTIFIC BACKGROUND STUDIES

1. GROUND ENVIRONMENT

Blackford, Paul A., Army Engineers Topographic Laboratories: Sand and Dust.

Cormier, René V., Air Force Cambridge Research Laboratories: Low Operational Temperature, Low Absolute Humidity, High Relative Humidity with Low Temperature, Temperature and Windspeeds Associated with High Precipitation Rates, Blowing Snow, Snowload, High and Low Pressure, High and Low Density.

Dodd, Arthur V., Army Natick Laboratories: High Relative Humidity with High Temperature.

Grantham, Donald D., Air Force Cambridge Research Laboratories: High Absolute Humidity, Windspeed, Ice Accretion.

Gringorten, Irving I., Air Force Cambridge Research Laboratories: High Temperature Cycle, High Withstanding Temperature, Low Operational and Withstanding Temperature and Duration, Windspeed, Hail Size.

Kantor, Arthur J., Air Force Cambridge Research Laboratories:
Ozone Concentration.

Lenhard, Robert W., Air Force Cambridge Research Laboratories:
High Operational Temperature, Operational and Withstanding Precipitation Intensities.

McPhilimy, Harry S., Army Engineer Topographic Laboratory:
Sand and Dust.

Riordan, Pauline, Army Natick Laboratories:
Record Extremes for High and Low Temperature, Precipitation Rate, Record Snow Depths.

Salmela, Henry A., Air Force Cambridge Research Laboratories:
Low Operational Temperature, High Absolute Humidity, Operational Precipitation Intensity.

Sissenwine, Norman, Air Force Cambridge Research Laboratories:
High Operational Temperature, High Temperature Cycle, High Withstanding Temperature, Low Operational Temperature, Windspeed, Operational and Withstanding Precipitation Intensities, Raindrop Spectra, Snowload Ice Accretion.

Tattelman, Paul I., Air Force Cambridge Research Laboratories:
High Operational Temperature, Windspeed, Ice Accretion, Raindrop Spectra.

2. NAVAL ENVIRONMENT

Surface:

Baker, Samuel E., Naval Weather Service Command (Consultant):
High and Low Operational and Withstanding Temperature, High Relative Humidity with High Temperature, Low Relative Humidity with High Temperature, Withstanding Windspeed, High and Low Surface Water Temperature.

Cormier, René V., Air Force Cambridge Research Laboratories:
Wind with High Temperature Cycles, High Withstanding Temperature Cycle, Cold Withstanding Temperature Duration, Low Absolute Humidity, High Relative Humidity with High and Low Temperature, Snowloads, High and Low Density.

Crutcher, Harold L., Naval Weather Service Command (Consultant):
Co-author with Baker, and Ice Accretion.

Meserve, Joseph M., Naval Weather Service Command (Consultant):
Co-author with Baker.

Air:

National Climatic Center, Naval Weather Service (Consultants):
High and Low Temperature.

3. AIR (WORLDWIDE) ENVIRONMENT

1 to 30 km:

Cormier, René V., Air Force Cambridge Research Laboratories:
Temperature Associated with Precipitation Rate, Horizontal Extent of Precipitation.

Grantham, Donald D., Air Force Cambridge Research Laboratories:
High Absolute Humidity.

Gringorten, Irving I., Air Force Cambridge Research Laboratories:
Hail Size.

Kantor, Arthur J., Air Force Cambridge Research Laboratories:
Ozone Concentration.

Richard, Oscar E., USAF Environmental Technical Applications Center:
High and Low Temperature with Coincident Densities, High and Low Absolute Humidity, Windspeed, Wind Shear, High and Low Pressure, High and Low Density with Coincident Temperature.

Sissenwine, Norman, Air Force Cambridge Research Laboratories:
High Absolute Humidity, Precipitation Intensity, Raindrop Spectra, Water Concentration.

Snelling, Hilda J., USAF Environmental Technical Applications Center:
Co-author with Richard.

Tattelman, Paul I., Air Force Cambridge Research Laboratories:
Raindrop Spectra.

30 to 80 km:

Cormier, René V., Air Force Cambridge Research Laboratories:
Ozone Concentration.

Cole, Allen E., Air Force Cambridge Research Laboratories:
High and Low Temperature with Coincident Density,
High and Low Pressure,
High and Low Density with Coincident Temperature.

Hinteregger, H. E., Air Force Cambridge Research Laboratories:
X and UV Radiation.

Kantor, Arthur J., Air Force Cambridge Research Laboratories:
Windspeed, Wind Shear.

Yates, G. K., Air Force Cambridge Research Laboratories:
Cosmic Particles.

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SYNOPSIS OF BACKGROUND MATERIAL FOR MIL-STD-210B, CLIMATIC EXTREMES FOR MILITARY EQUIPMENT

I. Introduction

1. BACKGROUND

This document was prepared to support a revision of Military Standard 210 (MIL-STD-210), Climatic Extremes for Military Equipment (Department of Defense[1]). The custodianship and preparing activity responsibility of this Standard, which was established in the Army in 1947, was transferred to the Air Force's aeronautical facilities at Wright-Patterson AFB shortly after initial publication in 1953. It has since been assigned to the Air Force's Electronics System Division (ESD) at L. G. Hanscom Field, Bedford, Massachusetts with the co-located Design Climatology Branch of the Air Force Cambridge Research Laboratories responsible for the scientific expertise needed for maintaining and/or revising the Standard.

(Received for publication 18 January 1974)

1. Department of Defense (1957) Military Standard, Climatic Extremes for Military Equipment, MIL-STD-210A, 2 August 1957, Standardization Division, Office of the Assistant Secretary of Defense, (Supply and Logistics), Washington, D.C.

1.1 Origin of MIL-STD-210

MIL-STD-210 is an outgrowth of structural and operational failure during World War II of combat and support equipment which were not carefully designed to withstand the extremes of climate to which the global conflict had subjected them. The Standards Agency of the Munitions Board formed a DoD committee in 1947, to study the conflicting differences of climatic extremes as used by the Army, Air Force, and Navy in testing, and to recommend the best limits.

In 1951, U.S. Army Quartermaster Report No. 146 "Climatic Extremes for Military Equipment" (Sissenwine and Court[2]) was published and provided surface-level land and sea extremes considered applicable to military operations with low risk. Extremes for short term storage and transit were also included. Report No. 146 served as the basis for the first edition of MIL-STD-210, published in 1953 and declared mandatory for use by the three Services by the DoD prefatory statement. A revised version, MIL-STD-210A, adding some upper air data, was published on 2 August 1957.

1.2 Necessity for Revision

Authors of Report No. 146 intended that the given climatic extremes be mandatory design criteria and used as a basis for testing against these goals. In the final writing, however, the purpose of MIL-STD-210 was modified to read, "to establish limits not to be exceeded in normal design requirements". In other words, MIL-STD-210 became a restriction for establishing design extremes not to be exceeded, but not a requirement that these extremes be the goals for military equipment. Thus, almost any values for operational requirements within these extreme limits could be established by the using Departments and the purpose of standardization within the three Services was not accomplished.

These discrepancies were severely criticized in a Final Report of the Working Party for General Support Equipment, JTCG, TACS, 5 October 1966, Department of Defense[3]. They found significant conflict with regard to environmental extremes within a number of DoD documents such as: AR 705-15, Operations of Materiel under Extreme Conditions of Environments; AFR 80-31, Climatization Program for Air Force Material Within the Sensible Atmosphere; MIL-STD-210, Climatic Extremes for Military Equipment; MIL-STD-202, Test Methods for

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2. Sissenwine, N., and Court, A. (1951) Climatic Extremes for Military Equipment, Report No. 146 Environmental Protection Branch, Research and Development Division, Office of the Quartermaster General, U.S. Army, Washington, D.C.

3. Department of Defense (1966) Final Report - 1st Task, Working Party for General Support Equipment, Revised 5 October 1966, Joint Technical Coordinating Group for Tactical Air Control Systems Projects - JTCG - TACS, The Pentagon, Washington, D.C.

Electronic and Electrical Component Parts; MIL-STD-810, Military Standard Environmental Test Methods; MIL-STD-170, Moisture Resistance Tests; and MIL-STD-169, Extreme Temperature Cycle.

They further indicated that frequently one Service will not accept another Service's equipment because of the environmental extreme to which it was designed. An example of this is high temperatures, used in design which range from 105°F in AR 705-15 to 160°F in most of the MIL-STDS. They recommended that a committee be established to consolidate existing documents so as to eliminate these design differences. Moreover, writers of specifications over the years have been using MIL-STD-210A extremes in specifications where they were not applicable, thereby adding to the expense and bulk, and reducing effectiveness of military equipment.

Thus, differing design extremes among the three Services, misuse of the MIL-STD-210A as presently worded, possibility of providing more accurate and additional extremes through a vastly improved climatological data base, and maturing concepts in the application of climatic information in design, led to DoD agreement that MIL-STD-210A should be completely revised.

Appendix A gives a chronology of the revision process. It includes the decisions and recommendations reached at a number of tri-Service meetings initiated in 1967 by the Design Climatology Branch, and views of the Joint Chiefs of Staff (JCS[4]) on acceptable design risks and areas of operations forwarded through and thus supported by the Office of Assistant Secretary of Defense.

2. REVISED MIL-STD-210 CONCEPT

MIL-STD-210B contains fundamental and noteworthy changes in concept from MIL-STD-210A (see Appendix A for details). Major changes are:

(1) Extremes are criteria for design as opposed to extremes not to be exceeded in design.

(2) Extremes are only for the unmodified natural environment (as opposed to tents, boxcars, etc...).

(3) Extremes are separated into three categories—"ground", "naval surface and air", and "worldwide air".

(4) Only worldwide extremes are presented (as opposed to regional breakdowns like arctic winter, moist tropics, hot desert).

4. Joint Chiefs of Staff (1969) Views of the Joint Chiefs of Staff Regarding the Establishment of Climatic Extremes as Mandatory Design Criteria for Standardized Military Equipment, in Memorandum for the Secretary of Defense, JCSM-502-69, 12 August 1969, Subject: Military Standard MIL-STD-210A, Climatic Extremes for Military Equipment.

(5) The two types of extremes are for operations and withstanding, rather than operations and short term storage and transit.

(6) Extremes that only have a near zero chance of being equalled or surpassed are provided as goals for designing equipment where operational failure due to an environmental extreme would endanger life.

(7) Extremes for operations are generally changed, insofar as possible, from extremes equalled or surpassed on 10 percent of the days (three days) to 1 percent of the hours (about seven hours) in the most severe month in the most severe area.

(8) Extremes with a greater likelihood of occurrence than the design criteria are presented.

(9) More climatic elements, also some surface oceanographic parameters, are included.

(10) Extremes extend to 262,000 ft (80 km) as opposed to approximately 98,000 ft (30 km).

(11) Extremes are generally given in both English and metric units.

(12) Polar and tropical atmospheres available in MIL-STD-210A are not included in 210B since these are not typical and not extreme conditions. The models in "U.S. Standard Atmosphere Supplements[5]", a GPO publication, should be utilized for tables of typical atmospheric conditions at tropical through polar latitudes (each 15^{O}), winter and summer.

An elaboration on the more substantive and important changes is presented in the following subsections.

2.1 Unmodified Natural Extremes

MIL-STD-210A contains a set of extremes entitled "short-term storage and transit". One such value, $160^{O}F$ for air within closed storage in a desert, has frequently been used by designers as the actual temperature attained by the equipment. Attempts to design accordingly have sometimes met with great difficulty and/or unnecessary equipment cost.

The storage extreme of $160^{O}F$ in MIL-STD-210A was not the temperature attained by equipment, but rather the air temperature observed in closed parked aircraft and tents in hot deserts for a short time period during the midday heat. It was presented for standardization over 20 years ago by one of the authors of this report (Mr. Sissenwine in Sissenwine and Court[2]) without taking into account the fact that if equipment with high thermal capacity were stored in these locations, lower air temperatures would be attained. A unique peak of $160^{O}F$ in the surrounding air for all material in storage is unrealistic.

5. U.S. Standard Atmosphere Supplements (1966) U.S. Government Printing Office, Washington, D.C., pp. 78-80.

Extremes induced in equipment are too dependent upon physical properties of the equipment and conditions of exposure for a single value to be specified. One cannot hope to specify the infinite number of intermediate induced conditions which can occur in storage. To illustrate, consider the high temperature extreme for which a small rocket should be designed. Typical long term storage of such ordnance might be in an underground facility in friendly territory. High temperatures attained within the rocket, even if this facility were in a hot desert, would be far less than in a desert combat zone where such ordnances could be used and so this situation is not applicable to MIL-STD-210B. Next consider some major depot facility in a desert combat zone where these rockets may be stacked. Stacks could be in crude warehouses, which become quite hot, or under a canopy to provide protection from sun and sand. Extremes of temperature in rockets so located would probably be less than the maximum possible, however, since some of the solar energy would be interecepted by the storage facility and not reach the rockets. The most likely condition of extreme temperature in storage is in some forward operating area in the hot desert where these rockets are stacked and left directly exposed to the sun or, perhaps, covered with a tarpaulin. Rockets on which solar energy is directly incident, those on top, will attain the highest temperature in an uncovered stack. Rockets under, but in direct contact with, a tarpaulin may come to either a higher or lower temperature than similarly placed uncovered rockets, depending upon the relative thermal radiation emissivities of rockets and tarpaulin and the conductivity of the tarpaulin.

Rockets should then be designed for the temperature they would reach at the top of the stack, when exposed to the several ambient extremes pertinent to the thermal equilibrium. This is more realistic than designing for a storage air temperature cycle established because air trapped under special conditions, such as in a closed empty compartment of an airplane parked in the desert, has been observed to attain 160°F.

For these reasons it was decided that MIL-STD-210B should contain only the most meaningful extreme. The extreme that can be specified with scientific confidence is that of the ambient conditions to which the storage facility is exposed, not some air temperature in '' storage which is dependent upon the storage situation. A basis exists for selecting ambient extremes, that is, frequency distributions of observations obtained on a routine basis. Analogous statistics of temperatures in a storage are not available; only spot readings for very special conditions.

The temperature induced in the materiel itself in storage needs to be determined by the engineers responsible for final design, either by theoretical modelling of the natural environment or by actual exposure to simulated or natural conditions. Useful empirical internal temperature data may be obtained by exposing

materiel in hot deserts and polar areas. Unfortunately, obtaining such data during the occurrence of exact MIL-STD-210B extremes may not be easily obtained. If detailed records of the natural environment are kept during the period of storage, it is possible to extrapolate the internal temperatures of the materiel to a fairly realistic extreme. Suppose that a hot dry diurnal cycle with a peak temperature of 125°F is standard for the "withstanding" extreme. Also, assume that during the period of test storage of a certain piece of equipment in a desert test center, the free air temperatures did not exceed 115°F. It would then make sense to add about 10°F to the internal temperatures attained during the desert exposure to arrive at realistic design information.

2.2 Use of Climatic Extremes in Testing

More severe extremes than those given in MIL-STD-210A have frequently been used in equipment testing to provide so-called <u>aggravated</u> tests. An example of this is the humidity test in MIL-STD-810A. This test includes a temperature of 71°C (160°F) at a relative humidity of 95 percent for a period of not less than 6 hrs. Such conditions are completely unrealistic. The question of its pertinence boils down to the correlation of degradation under such test conditions with degradation under natural conditions. Only when such correlation has been scientifically supported are such tests valid.

It is conceivable that an <u>accelerated</u> test which involves laboratory exposure to many cycles of the simulated natural extremes, but in much shorter time than would be encountered in nature, could provide some indication of the long degradation of a piece of equipment. The number of exposures should be related to the number of cycles expected in a natural lifetime. Also, the possibility that repeated occurrence could lead to an unrealistic buildup, must be evaluated.

In summary, aggravated tests utilizing extremes far beyond those occurring in nature should be used only when the results of the test can be correlated with degradation in the natural environment from past investigations for the specific class of items being tested. Accelerated tests should also be evaluated for the effect of persistent extreme conditions.

2.3 Operational Extremes

It would be prohibitive in cost and/or technologically impossible to design military equipment to operate anywhere in the world under the most extreme environmental conditions ever recorded. For this reason, military planners are usually willing to take a calculated risk and accept equipment designed to operate under environmental stresses for all but a certain small percent of the time. This implies a temporary postponing or stopping of a field operation until a change to more favorable environmental conditions occurs.

The operational extremes in MIL-STD-210A were based on such a philosophy. They were values determined by scientific judgment not to be surpassed on more than 10 percent of the days (three days) of the most extreme month. With such a criterion, unfortunately, it is impossible to determine with sufficient resolution the duration—number of hours—that equipment will be inoperable. And since military operations can take place over a whole range of time scales, this severely restricts the utility of the extremes in MIL-STD-210. The choice of this measure—days per month—was dictated by the type of data—for example, daily maximum temperature—in existence when the original MIL-STD-210 was prepared.

Design criteria for operations recommended for MIL-STD-210B are based, where possible (especially the surface extremes), on hourly data from which it is possible to approximate the total number of hours that a given value of a climatic element is equalled or surpassed in the most extreme month and area of the world. This statistic is much more meaningful for military operations. If a value of a climatic element occurs (or is surpassed) in about seven hourly observations in the 744 hourly observations of a 31-day month, then this value occurs roughly 1 percent of the time (hours); if it occurs (or is surpassed) in 74 out of 744 hourly observations, then it occurs 10 percent of the time, etc....

The value on the high end of a cumulative frequency distribution that occurs (or is surpassed), for example, 1 percent of the time is loosely and variously spoken of as the 1 percent extreme, or the extreme that occurs with a 1 percent risk, or with 1 percent probability, or with a 1 percent chance, or the upper 1 percentile extreme. Analogously, the value on the low end of a cumulative frequency distribution that has the same probability, has a percent exceedance of 99 percent. For the sake of uniformity and to minimize confusion, throughout the rest of this document both the high and low extremes of climatic elements equalled or surpassed 1 and 99 percent of the time will be referred to as the high or low 1 percent extreme. Along the same lines, we will refer to the high and low 1/2 percent, 5 percent, 10 percent, 20 percent, etc., extremes.

As mentioned in Appendix A, based on guidance from the Office of the Assistant Secretary of Defense (JCS[3]), the 1 percent extreme is recommended as the operational design criteria for all but two climatic elements—surface low temperature, where the 20 percent extreme is recommended, and surface rainfall rate where the 1/2 percent extreme is recommended. The 20 percent risk is accepted because lower temperatures associated with lower risks are extremely limited in areal extent. Also, at temperatures below the 20 percent low temperature extreme, -60°F, military operations involving exposed individuals are highly improbable if not impossible from a human capabilities standpoint. The 1 percent rainfall rate is not used because its use would result in far more than

the nominal (geographically-limited, worst area/worst month) 7.4 hr of inoperability. This is because high rainfall intensities are not limited to small geographic areas on the earth's surface but occur over widespread areas in the rainy tropics—many worst areas—and are not limited to one peak worst month. In monsoonal tropics, there can be several months with little difference in rain regimes.

In the typical case where extremes occur essentially during one worst month, the 7.4 hr of inoperability associated with the 1 percent extreme would probably not occur consecutively, but on two or three ocassions in increments of 2 to 3 hr.

A most direct way of calculating the 1 percent (or any other percent) extreme is to list the hourly observations of a climatic element from a given month in order of increasing or decreasing value. Knowing the total number of observations, it is straightforward to calculate the value equalled or surpassed in 1 percent of the observations. If there are a large number of observations in the listing—data from the worst month taken from many past years—the 1 percent extreme so determined would most probably represent the value to be equalled or surpassed in 1 percent of the hourly observations per worst month in future years.

If only a few years of data are available, special care must be taken to insure statistical representativeness of extremes derived as such samples are often unstable. One can plot the available values on normal probability paper using one of a number of plotting rules, check the normality by determining if the points lie on a straight line and, if normal, extrapolate the line for an estimate of the 1 percent (or other percent) extreme.

2.4 Withstanding Extremes

Equipment should be designed to withstand extremes more severe than the operational extremes without incurring irreversible damage, and be capable of operations when conditions ameliorate. Such extremes are termed "withstanding" values.

Analagous to the operational extremes, it is unwise to attempt to design for the most extreme value of an element which has a chance, however slight, of occurring during the expected duration of field exposure of the equipment. Therefore, military planners are willing to accept equipment which will withstand all but the most unlikely values of a given element.

Unlike the operational extreme where the percent risk is generally the percent of time (hours) of equipment inoperability during the most extreme month, the percent risk for withstanding extremes is the risk that a given value of a climatic element will occur (or be surpassed) once in the expected duration of exposure of the equipment in the most extreme area. As with the operational extremes,

the withstanding extremes that have a 1, 5, 10, and 20 percent chance of occurring are referred to as the 1, 5, 10, and 20 percent withstanding extremes.

Since expected duration of exposure (EDE) of equipment is usually measured in years, distributions of yearly extreme values of an element for a large number of years are the basis of withstanding extremes.

The most straightforward approach for determining withstanding extremes would be to obtain the extreme value of a given climatic element in each of a number of yearly periods equal to the equipment planned lifetime. From the distribution of maximum extremes for a period of years (the EDE), one could determine—as discussed in Section 2.3—the value that is likely to occur in an EDE with 1, or 10, or 20 percent chance depending on the risk desired. In order to have a reliable estimate of a value for these risks, a large sample of yearly periods would be needed. However, one can see that even for an EDE of 10 years, a record of 1000 years is needed to obtain the extreme value attained in 100 independent 10 year periods. Fortunately, extreme value statistical theory is available to determine the values of an element to be expected in a given number of years for specified probabilities.

The distribution of annual extremes of a given element generally fit one of limited number of theoretical statistical distributions. The annual extremes of many elements fit a Gumbel distribution (Gringorten[6]). If the annual extremes fit this distribution, they will then lie on a straight line when plotted on graph paper called extreme probability paper. If not, then other distributions may be assumed and the values plotted on probability graph paper corresponding to the particular distribution assumed. From the plot of the annual extremes on such kinds of probability paper, it is possible to directly obtain the value of an element that will occur once in a given number of years, the so-called return period.

The return period chosen for determining the withstanding extreme depends on the EDE of the equipment and the acceptable risk. For instance, for a 10 year EDE and a 10 percent risk, one would choose a value that has a return period of approximately 100 years, so that there is roughly a 10 percent risk of that value occurring in any 10 year period. For equipment with an EDE of 5 years and again a 10 percent risk, one would select the extreme that has a return period of approximately 50 years. Varying the risk percent for a value with a return period of 100 years, there is approximately a 25 percent chance of that value occurring in any 25 years, a 10 percent chance in any 10 years, and a 1 percent

6. Gringorten, I.I. (1960) Extreme Value Statistics in Meteorology - A Method of Application, AFCRL-TN-60-442.

chance in any 1 year. The following table lists the return periods* for risks of 1 and 10 percent for equipment EDE's of 2 to 25 years.

EDE(yr)	Return Periods (yr) 1 Percent Risk	Return Periods (yr) 10 Percent Risk
2	200	20
5	500	50
10	1000	100
25	2500	250

For each item of equipment, the likely EDE must be considered separately for each climatic element. For example, expected durations of exposure to tropical humid conditions may frequently be 10 or 25 years whereas expected exposure to the very cold extremes of the arctic for the same item might not exceed 2 years.

The technique described above was that used (except where noted) to calculate the withstanding extremes presented in Chapters II and III that follow. Withstanding extremes were not calculated for all surface elements because of the inapplicability of the withstanding concept for some elements; nor were they determined for climatic elements aloft, because equipment is not stored there.

In establishing the withstanding design criteria, an initial approach could be to select—as the withstanding extreme for a particular element—the value which will occur on the average, once in the EDE. If this value is accepted, however, the equipment may well be irreversibly damaged in its lifetime and this might happen in the first few years. This is probably a higher risk than is acceptable. At the other end of the risk spectrum, accepting a risk of only 1 percent also seems unreasonable because, as illustrated above, it implies that for an EDE of 10 years, an extreme can be expected to occur only once in 1000 years. A 10 percent risk, implying return periods of 20, 50, 100, and 250 years for EDE's of 2, 5, 10, and 25 years respectively, is more logical and was recommended by the Office of the Assistant Secretary of Defense (JCS[4]) as the withstanding design criteria (see Appendix A). Since extreme values are selected from the most severe area, the overall probability of occurrence during the EDE of most equipment will be lower.

*These are only approximate (but adequate for MIL-STD-210B purposes) return period values. For higher risk percents, the apparent relationship between percent risk, planned lifetime, and return period presented in the text above and evident in the accompanying table does not rigorously hold.

3. REPORT ORGANIZATION/CONTENTS

Chapters II, III, IV and V that follow present the MIL-STD-210B extremes and scientific support for them. This essentially is a synthesis in a simplified and consistent format of the various individual background studies that were prepared by diverse Air Force, Army, and Navy group members and their associates. This synthesis provides the essence of each of the individual reports so that MIL-STD-210B users need to consult only a single document for an elaboration on the extremes presented in MIL-STD-210B.

Chapter II deals with extremes of the ground environment, while Chapter III presents extremes for the naval surface and air environment. These include extremes found over the open oceans, coasts, and ports. The original Navy study for MIL-STD-210B (Crutcher et al[7]) contains extremes from both the open ocean and navigable coastal ports. Since equipment destined for shipboard use should be designed to operate in and withstand the extreme conditions found in and over both the open ocean and in coastal ports, the only extremes presented for each element are those from the severest of these two locations, be it open ocean or coastal port. Chapter IV presents extremes for the worldwide air environment for altitudes up to 262,000 ft (80 km).

Within each of Chapters II through IV, the different climatic elements are presented in numbered chapter subsections in a general order or priority; also for elements that are common to each of these chapters, the same number for a particular element generally is used. Within each of the chapter's element subsections, there are further breakdowns. For operational criteria, the highest/lowest recorded value of an element, the design criteria, and the less severe extremes used for guidance when designing for the design criteria is not feasible, are presented. Then the withstanding extremes for surface conditions are given. Insofar as possible, the same numbers are used within chapters for these further subdivisions.

Appendix A, presenting the revision chronology, follows the references.

The table of contents for this document and for MIL-STD-210B is quite general and contains elements and items within elements for which data are not yet available for a study and/or for which a study has not yet been undertaken. A note, contained in the appropriate location within the body of the chapters for such elements, indicates this status. This policy was adopted to facilitate the updating and broadening of contents in MIL-STD-210B.

7. Crutcher, H.L., Meserve, J., and Baker, S. (1970) Working Paper for the Revision of MIL-STD-210A to MIL-STD-210B, U.S. Navy, National Weather Records Center, Asheville, North Carolina.

II. Extremes for Ground Environment

1. TEMPERATURE

1.1 High Temperature

Temperatures discussed in this section were observed in standard meteor-oligical instrument shelters. They approximate temperatures of the free air in the shade about 5 or 6 ft above the ground. These high temperatures will normally be encountered only during strong sunshine and fairly light winds. The ground surface will attain temperatures 30 to 60°F higher than that of the free air, depending upon radiation, conduction, wind, and turbulence. Air layers very close to the surface will be only slightly cooler than the ground, but the decrease with height above the surface is exponential so that temperatures at 2 to 5 ft will be only slightly warmer than that observed in an instrument shelter.

The temperature attained by military equipment exposed to high temperatures will vary greatly with physical properties of the equipment affecting heat transfer and capacity, and with the type of exposure. (Probably the worst exposure is that of equipment placed on the ground in the direct sunshine.) However, surface and internal temperatures that the equipment will attain cannot always be readily calculated, since some physical properties affecting heat transfer are only roughly known.

The heat load from a realistic diurnal air temperature and solar radiation cycle (data that can be provided from meteorological records) make up only a part

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of the heat transferred to the equipment. The equipment temperature will also be dependent on solar radiation reflected to it from the ground, long wave radiation from the heated ground, long wave radiation to the cold sky, scattered solar radiation from the sky and nearby clouds, the vertical temperature distribution in the free air surrounding the equipment, and total ventilation from wind and turbulence.

1.1.1 HIGHEST RECORDED (Riordan[8])

Most extreme high temperatures have been recorded near the fringes of the deserts of North Africa and southwestern United States in shallow depressions where rocks or sand reflect the sun's heat from all sides. In the Sahara, greatest extremes are recorded toward the leeward coast, after the air has passed over the heated desert. The world's highest recorded temperature is 136°F recorded at El Azizia, Libya on 13 September 1922. El Azizia is located in the northern Sahara at 32°32'N, 13°01'E, elevation 367 ft. At least 30 years of observations are available for this station. Besides the 136°F reported, maximum temperatures of 133°F and 127°F for August and June have also been observed.

1.1.2 OPERATIONS

1.1.2.1 1, 5 and 10 percent Extremes (Tattelman et al[9])

The operational extreme, provided in the original publication of MIL-STD-210 in 1953, is 125°F. It is the temperature attained as a daily maximum on three consecutive days per year (generally the hottest month so that a 10 percent probability (3 out of 30 days) of being attained as a daily maximum during this month is approximated) over the hottest area of the world. For the revision of MIL-STD-210, the operational temperature extreme is based upon the distribution of all hourly temperatures, rather than maximum daily temperatures (see Section I.2.3).

Maps of the temperature exceeded 1, 2.5, 5, 10 and 20 percent of the time for the hottest month, based upon actual hourly temperature distributions, were available for North America (USAF GRD[10]). Time did not permit obtaining empirical distributions of hourly temperature for all other hot places, nor determination of the extent of hourly data available on a worldwide basis to develop such

8. Riordan, P. (1970) Weather Extremes Around the World, TR-70-45-ES, U.S. Army Natick Laboratories, Natick, Massachusetts.

9. Tattelman, P.I., Sissenwine, N., and Lenhard, R.W. Jr. (1969) World Frequency of High Temperature, AFCRL-69-0348, ERP 305.

10. USAF Geophysics Research Directorate (1960) Surface air temperature probabilities, also precipitation models, Handbook of Geophysics, The MacMillan Co., New York.

distributions. A statistical technique to determine the desired high temperature extremes for operation was employed.

An index was developed using the logic that highest temperatures will be found where monthly mean temperatures and the mean daily range are greatest. Good climatic records are readily available for both these measures of temperature on a worldwide basis. This very simple index may be expressed as

$$I = \bar{T} + (\bar{T}_x - \bar{T}_n),$$

where I is the index, $\bar{T}$ is the mean, $\bar{T}_x$ is the mean daily maximum, and $\bar{T}_n$ the mean daily minimum temperature for the month.

This index was correlated with the 1, 5, and 10 percent operational temperature extremes ($T_{1\%}$, $T_{5\%}$, and $T_{10\%}$) during the warmest month at thirty U.S. Weather Bureau stations in the contiguous United States for which such frequencies were readily available. From these correlations, regression equations (of the form, $T_{x\%} = aI + b$) were obtained by the method of least squares.

The temperature predictions from these equations were then checked against observed temperature extremes and the results indicated that the equations could be used to determine 1, 5, and 10 percent operational high temperatures extremes at those stations where hourly records were either nonexistent or not readily available.

Estimates of operational temperature extremes obtained using these equations are, for the most part (67 percent of the time), accurate to within 2 to 3°F; there is also a 5 percent chance that these estimates are 5 or 6°F higher or lower than the true 1, 5, and 10 percent operational temperature extremes.

Four hundred and fifty locations with high temperature were selected from around the world. Indices (I) for the warmest month were computed for these stations. Using these indices and the regression equations, the 1, 5, and 10 percent high temperature extremes at each of these stations were determined. From these temperatures, 1, 5, and 10 percent temperature extreme maps were prepared.

Figures 1, 2, and 3 show the temperatures equalled or exceeded 1, 5, and 10 percent of the time (hours) for the hottest month.

Northern Africa eastward throughout most of India is the hottest part of the world. Large areas attain temperatures of 110°F more than 10 percent of the time during the hottest month (Figure 3). However, northwest Africa is the only extensive area with temperatures of 120°F or greater as much as 1 percent of the time during the hottest month (Figure 1). This is the value associated with an index I of 134 for Araouane, French Sudan. The area to the north between this point and Tindouf and Boubernous in Algeria (which have indices of 131) may

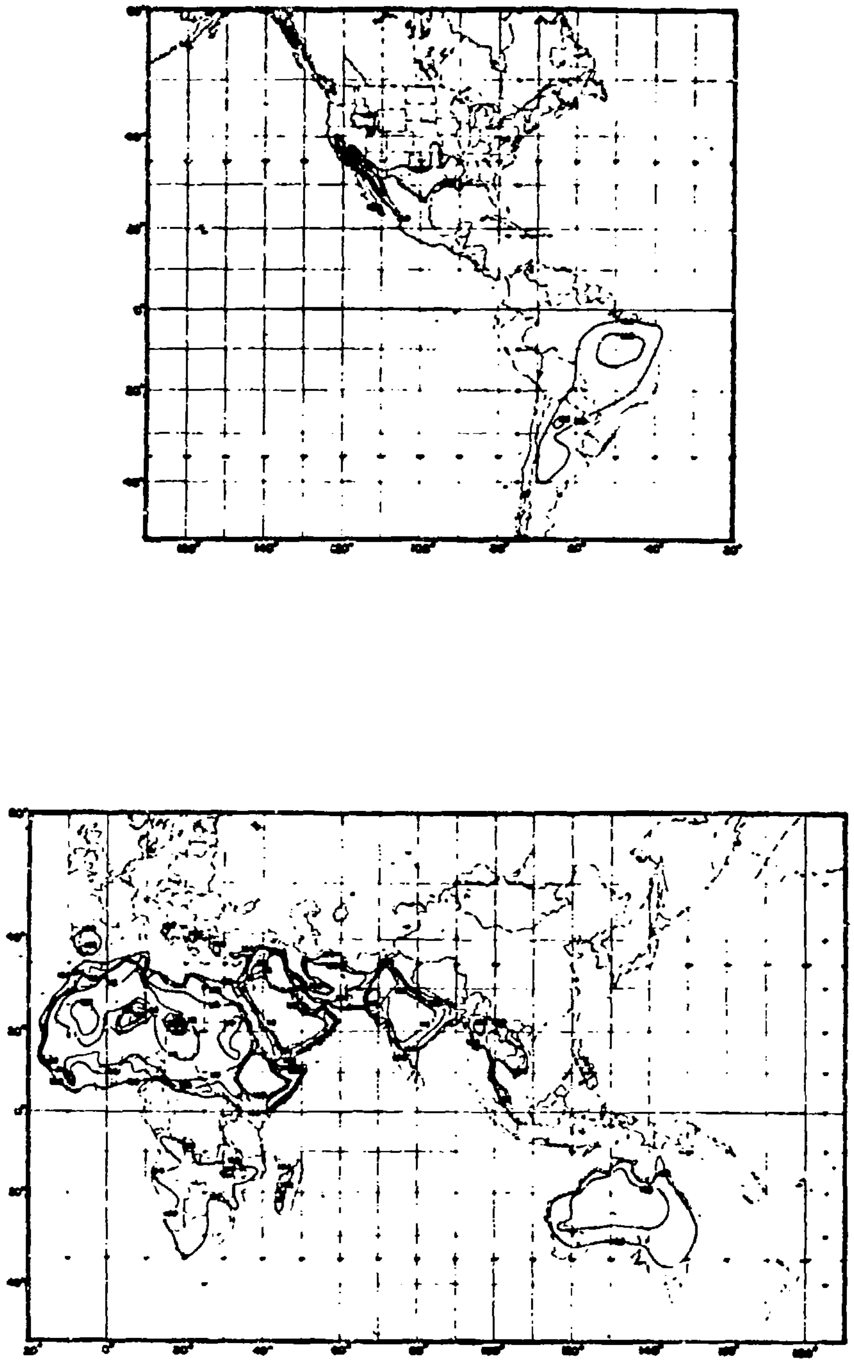

Figure 1. Temperature (°F) Equalled or Exceeded 1 Percent of the Hours of Hottest Month

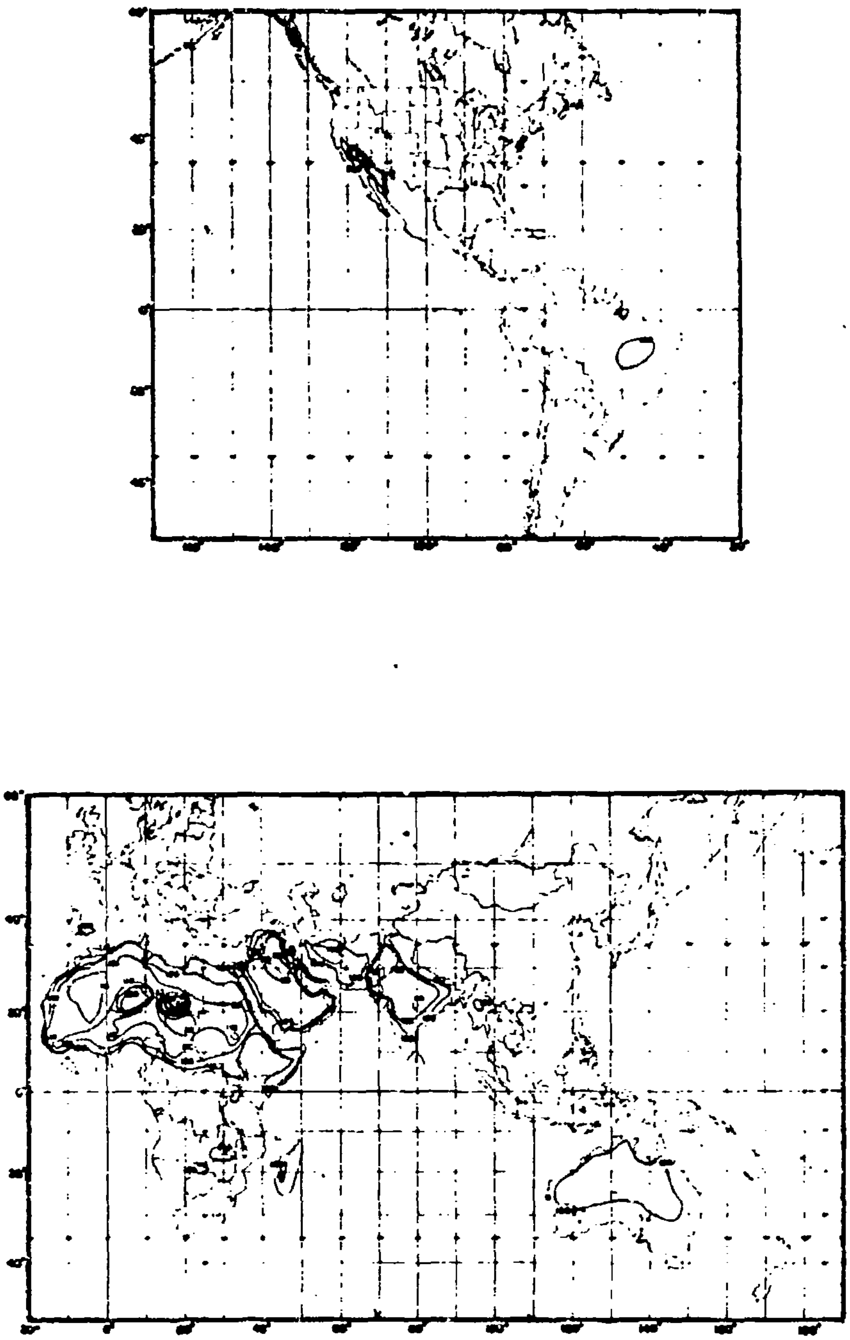

Figure 2. Temperature (°F) Equalled or Exceeded 5 Percent of the Hours of Hottest Month

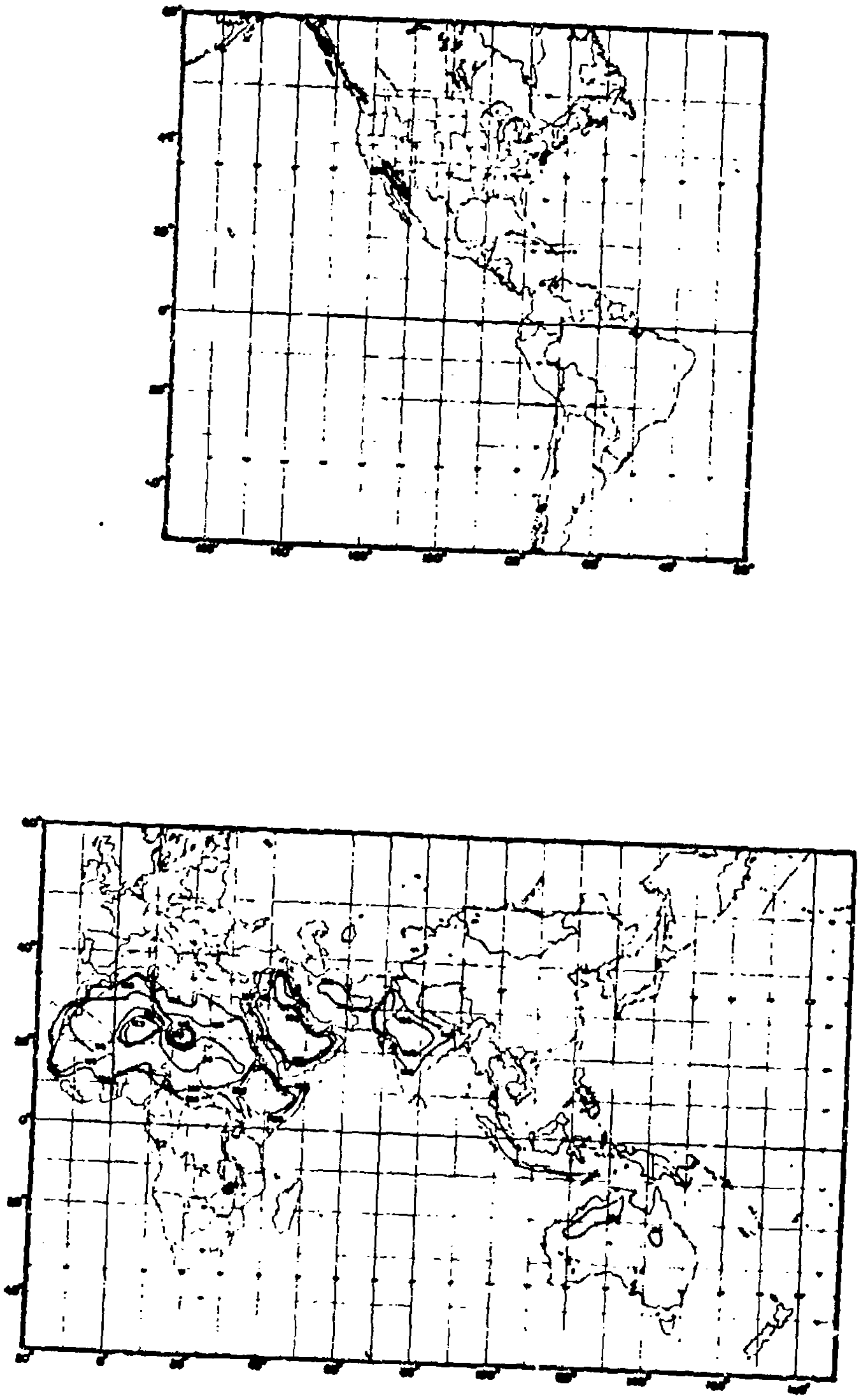

Figure 3. Temperature (^{o}F) Equalled or Exceeded 10 Percent of the Hours of Hottest Month

be even hotter but is so sparsely settled that temperature records are not available. El-Azizia, Libya, latitude 33°N, longitude 13°E, altitude 367 ft, the location of the world record high temperature of 136°F, has an index of only 100. It is therefore far removed from the area in which 120°F has a 1 percent probability.

Australia and South America have a substantial percentage of time with temperatures at or above 100°F, but the frequency of higher temperatures diminishes rapidly. Neither of these continents indicates temperatures at or above 110°F as much as 1 percent of the time during the hottest month.

The southwestern United States and a narrow strip of land in western Mexico can be considered exceedingly hot by world standards. A substantial part of this area experiences temperatures at or above 110°F more than 1 percent of the time during the hottest month. Located in this hot area is Death Valley which experiences 120°F temperatures 1 percent of the time and which has a record 134°F (10 July 1913), only 2°F less than the world record for El-Azizia.

If military materiel is to be designed for temperature sufficiently high to function any place in the world with only a 1 percent risk of inoperability during the warmest month of the year, then it must be designed for a diurnal cycle in which the air temperature attains a maximum of at least 120°F. The effect of solar, ground and sky radiation on the equilibrium temperature of equipment must be added to this cycle. This 1 percent extreme will be encountered in the area in the Sahara depicted in Figure 1 (and also at Death Valley, California). Temperatures of 120°F will also be encountered in hot deserts outside this area but less than 1 percent at the time of the hottest month.

For the 5 percent extreme, a diurnal cycle with a maximum temperature of 115°F is required. Areas in which military operations will thus be limited for 5 percent of the hours of the warmest month, include a moderate portion of the Sahara Desert and very small areas in the desert of southwest United States and the desert just northwest of the Persian Gulf.

For a 10 percent extreme, a diurnal cycle with a maximum temperature of 110°F is shown. This extreme is found in much of northern Africa and the Middle East. In Section III. 1. 1. 1. 2, evidence is given for a 10 percent high temperature extreme of 113°F from a coastal port. Therefore, this criteria should be used instead of 110°F.

With the temperature extreme for design established on the basis of the warmest month of the year, the number of hours this temperature is encountered during all other months will be less than in the warmest month.

1.1.2.2 Daily High Temperature Cycle (Gringorten and Sissenwine[11])

Hot extremes are always part of a well pronounced diurnal cycle. The daily maximum lasts only a couple of hours. However, it is accompanied by strong sunshine that causes equipment to attain temperatures considerably higher than the free-air values on which climatology maps are based. For this reason the hot extreme of temperature for operating (and withstanding) must be part of a realistic diurnal cycle including solar radiation. The cycle should also include windspeed, which serves as a limiting factor to heat intensification. The moisture content is also needed since the extremely low relative humidities that can be present during the hottest situations may be special design problems.

This study does not examine alternative methods for estimating heat stress. Specifically, it does not provide cycles of greatest solar insolation. Solar insolation is known to be greater at high-elevation deserts (and other elevated topography) than it is in the near-sea-level hot deserts mentioned; however, free-air temperatures are not as high. The assumption is made herein that equipment will, in general, reach higher temperatures in the hottest locations than in the "sunniest" locations; therefore, the high thermal-stress cycles developed herein are linked to instrument shelter free-air temperatures, a worldwide standard.

Typical locations for models of extreme temperature cycles are French West Africa and Death Valley, California. Since records for those areas are incomplete with respect to the diurnal cycle and associated measures of radiation, windspeed, and moisture, it was decided to study Yuma, Arizona. While not as hot as Death Valley, Yuma is in one of the hotter deserts near sea level and has a substantially detailed record of hourly observations that can be studied in depth. Patterns discerned by this study were then extrapolated to Death Valley to provide an estimate of the cycle associated with the 1 percent extreme temperature of 120°F.

The 1 percent high temperature extreme during Yuma's hottest month (July) is 111°F. In the period 1961 to 1968, there were 20 days during which the temperature rose to 111°F or higher. For these select days, the median maximum is 111°F and the median minimum is 83.5°F; the average temperature of each hour is shown in a diurnal cycle in Figure 4. The mean diurnal range is 27.5°F for these 20 hottest days, about the same as it is for other July days. A further analysis of the hourly temperature values shows that the 1 percent hottest days are very similar to one another and can provide a reliable diurnal cycle to be associated with the Yuma 1 percent value of 111°F.

11. Gringorten, I.I., and Sissenwine, N. (1970) Unusual Extremes and Diurnal Cycles of Desert Heat Loads, AFCRL-70-0332, ERP 323.

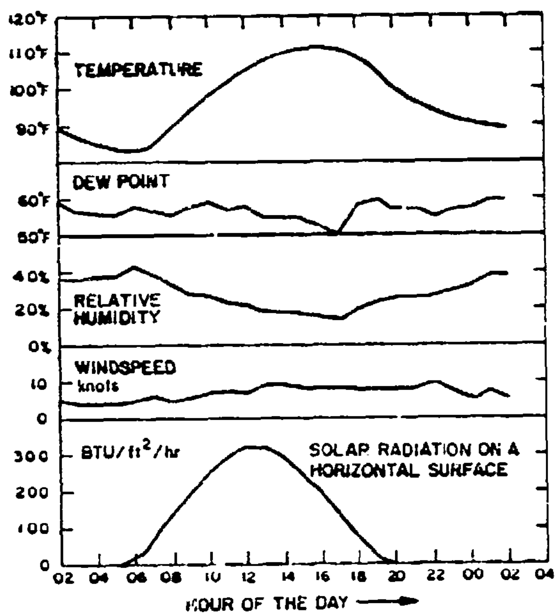

Figure 4. Yuma, Arizona, July Typical Diurnal Cycles of Temperature, Dew Point, Relative Humidity, Windspeed, and Solar Radiation Associated With Maximum Daily Temperature Equal to or Exceeding 111°F, Based on 1961-1968 Data

The median hourly dew points for the same 20 hottest July days are shown in Figure 4. The overall median is 57°F. The large diurnal temperature range yields a pronounced diurnal cycle of relative humidity that is out of phase with the smaller cycle of dew point.

The windspeed has a median value of 7 knots. The anemometer levels were known to be 20 to 27 ft above ground. While varying in the narrow limits of 4 to 9 knots, the wind still appears to have a diurnal cycle with maximum speed in the afternoon and minimum in the early morning.

Solar radiation on a horizontal surface has a noon value of 325 Btu $ft^{-2}h^{-1}$ decreasing to zero at 2000 LST and remaining at zero until 0500 LST the following morning.

Temperature cycles for the hottest day and for one and two days before and after each of the 20 hot days were also studied, and from these studies Table 1 was prepared.

Table 1 gives the ratio of the departure of each hourly temperature from the 1 percent extreme temperature (111°F for Yuma) to the diurnal range of temperature of the hottest day (27.5°F for Yuma). It also gives the ratio of windspeed departure from an anchor value to that anchor value, likewise for solar radiation. At Yuma, the anchor value for windspeed is 8 knots and for solar radiation 325 Btu $ft^{-2}h^{-1}$. These relationships are considered typical of even hotter near-sea-level deserts, and are provided as patterns of diurnal cycles of such locations in periods of extreme heat.

Table 1. Hourly Ratio of Temperature Departure From the 1 Percent Extreme Temperature to the Diurnal Temperature Range on the Hottest Days. The table also includes associated cycles of windspeed and solar radiation showing the hourly departure from the daily maximum as a fraction of that maximum

Item	Time of Day (hr)											
	1	2	3	4	5	6	7	8	9	10	11	12
Temperature, hottest day	0.84	0.88	0.88	0.93	0.98	1.00	0.96	0.84	0.62	0.47	0.35	0.26
1 day before	0.80	0.87	0.94	1.02	1.02	1.05	0.98	0.84	0.65	0.54	0.40	0.33
1 day after	0.76	0.80	0.87	0.87	0.94	0.94	0.91	0.80	0.65	0.54	0.40	0.31
2 days before	0.87	0.93	0.98	1.00	1.02	1.09	0.98	0.87	0.73	0.58	0.47	0.36
2 days after	0.87	0.89	0.93	0.93	0.96	0.98	0.94	0.84	0.73	0.62	0.51	0.42
Windspeed, hottest day	0.38	0.38	0.38	0.38	0.38	0.38	0.38	0.38	0.38	0	0	0
Radiation, hottest day	1.00	1.00	1.00	1.00	1.00	0.95	0.76	0.55	0.35	0.18	0.07	0

Item	Time of Day (hr)											
	13	14	15	16	17	18	19	20	21	22	23	24
Temperature hottest day	0.13	0.04	0.04	0	0.02	0.07	0.20	0.40	0.49	0.58	0.67	0.73
1 day before	0.26	0.14	0.11	0.07	0.11	0.14	0.22	0.40	0.51	0.58	0.69	0.76
1 day after	0.24	0.14	0.11	0.11	0.11	0.22	0.31	0.44	0.56	0.67	0.78	0.84
2 days before	0.31	0.24	0.20	0.09	0.14	0.18	0.29	0.49	0.58	0.62	0.73	0.74
2 days after	0.33	0.27	0.22	0.20	0.22	0.27	0.34	0.51	0.64	0.69	0.76	0.85
Windspeed, hottest day	0	0	0	0	0	0	0	0	0	0	0	0.38
Radiation, hottest day	0	0.07	0.18	0.35	0.55	0.76	0.95	1.00	1.00	1.00	1.00	1.00

A comparison of the above Yuma temperature statistics was made with records available from Death Valley—a location whose 1 percent extreme temperature is 120°F for each day that the temperature equalled or exceeded 120°F in July. The comparison led to the conclusion that the Yuma temperature cycle (Table 1) can be used to establish the temperature cycle associated with a 1 percent extreme temperature of 120°F. This cycle together with hourly temperatures one day before and after, and two days before and after the hottest day are shown in Table 2.

Figure 4 shows that for the selected sample of July days at Yuma, the hourly dew point has an overall median of 57°F. Data obtained during a Death Valley expedition (Sissenwine et al[12]) shows that the humidity varied from a relatively moist condition (45° to 50°F dew points) at places like the National Monument and Cow Creek to very dry conditions over desert dunes near Stove Pipe Wells; over the desert dunes on 10 and 11 August 1950, some 12 afternoon observations (1200 to 1700 hours) gave a median dew point of 19°F and a relative humidity of 4 percent.

Since a low moisture content causes the most critical drying during the hot extreme conditions, a rounded-value 20°F dew point is chosen, yielding the relative humidities associated with high temperatures in Table 2.

At Yuma, Arizona, July windspeeds on the hottest days are approximately 8 knots from 1000 to 2300 LST and 5 knots at other times. The anemometer height during the periods of record was 20 to 27 ft above the ground.

At Death Valley, California (1961 to 1969), the wind recorder at 1.5 to 2.0 ft height was read once daily to give the 24 hr movement of air across an evaporation pan. On 35 days when the maximum temperature reached or exceeded 120°F, the recorded movement had a median of 55 miles, thus giving an average windspeed of 2.3 mph at a height of 1.5 to 2.0 ft. This value was restored to hourly values using the Yuma ratios in Table 1 and extrapolated to a standard height of 10 ft using the power law,

$$\frac{V_{10}}{V_2} = \left(\frac{10}{2}\right)^{0.17} .$$

These hourly values are also listed in Table 2.

The report of Sissenwine et al[12] gives an average (or typical) noontime radiation on a horizontal surface at Death Valley, California, between 20 July and 12 August with clear skies, of 82.5 Langleys/hr. At Yuma, Arizona, the July Eppley Pyrheliometer records yielded a noontime average of 325 Btu $ft^{-2}h^{-1}$

12. Sissenwine, N., Meigs, P., and Anstey, R. (1951) Studies on Clothing for Hot Environments, Death Valley 1954 Part II Environments, Dept. of Army, Research & Development EPS No. 178, Washington, D.C.

Table 2. Diurnal Cycles of Temperature and Other Elements for Days When the Maximum Temperature Equals or Exceeds the Operational 1 Percent Extreme Temperature (120°F)

Item	Time of Day (hr) 1	2	3	4	5	6	7	8	9	10	11	12
	Temperature (°F)											
Hottest Day	95	94	93	92	91	90	91	95	101	106	110	112
1 day before or after	96	95	93	92	91	90	92	96	100	104	108	111
2 days before or after	94	93	92	91	90	89	91	95	98	102	105	108
	Other Elements											
Relative Humidity (%) (dp = 20°F)	6	7	7	8	8	8	8	6	6	5	4	4
Windspeed (mph)	6.1	6.1	6.1	6.1	6.1	6.1	6.1	6.1	6.1	9.7	9.7	9.7
Solar Radiation (Btu $ft^{-2}h^{-1}$)	0	0	0	0	0	18	85	160	231	291	330	355

Item	Time of Day (hr) 13	14	15	16	17	18	19	20	21	22	23	24
	Temperature (°F)											
Hottest Day	116	118	119	120	119	118	114	108	105	102	100	98
1 day before or after	113	116	117	118	117	115	112	108	104	101	98	96
2 days before or after	110	112	114	116	115	113	111	105	102	100	98	96
	Other Elements											
Relative Humidity (%) (dp = 20°F)	3	3	3	3	3	3	3	4	5	6	6	6
Windspeed (mph)	9.7	9.7	9.7	9.7	9.7	9.7	9.7	9.7	9.7	9.7	9.7	6.1
Solar Radiation (Btu $ft^{-2}h^{-1}$)	355	330	291	231	160	85	18	0	0	0	0	0

or roughly 88.0 Langleys/hr. This difference is probably due to increased absorption of radiation by the atmosphere over Death Valley since Death Valley is 178 ft below sea level compared to Yuma's elevation of 206 ft above sea level.

The absorption of solar radiation is related to the thickness (by mass) of air that is penetrated; the following relation is acceptable as an initial assumption for solar radiation at pressure, p:

$$I = I_o e^{-ap} \tag{1}$$

where I is the radiation incident on a horizontal surface at a level with a pressure, P, I_o is the solar constant for radiation on a horizontal surface above the atmosphere, 117 Langleys/hr, and a is a constant to be determined which depends on the properties of the air mass through which the solar radiation penetrates.

For Yuma,

$$I_1 = I_o e^{-ap_1} \tag{2}$$

and for Death Valley

$$I_2 = I_o e^{-ap_2} \quad . \tag{3}$$

Eliminating I_o between Eqs. (2) and (3), we obtain

$$\frac{I_1}{I_2} = \frac{e^{-ap_1}}{e^{-ap_2}} \quad . \tag{4}$$

For Yuma and Death Valley $I_1 = 88.0$, $I_2 = 82.5$, $p_1 = 1006$ and $p_2 = 1020$. Solving for a, the value of 0.00464 mb^{-1} is obtained. This assumes that the air mass properties at Yuma and Death Valley are the same.

The hottest locations in the Sahara desert are all at about 1000 ft altitude. The standard atmospheric pressure is 977 mb for that altitude. Solving Eq. (1) for 977 mb and a equal to 0.00464 mb^{-1} yields 100.8 Langleys/hr or 369 Btu $ft^{-2}h^{-1}$. This value is just 14 Btu $ft^{-2}h^{-1}$ higher than the value of 355 Btu $ft^{-2}h^{-1}$ contemplated for adoption in a revision to Quadripartite Standardization Agreement 200 (Brierly[13]) for a joint American, British Canadian, and Australian Armies

13. Brierly, W.B. (1972) Copy of U.K. Revision to Current QSTAG 200, U.S. Army Engineer Topographic Laboratories, ETL-GS-EC letter of 12 September 1972 to Mr. Norman Sissenwine, AFCRL (LKI).

standardization program. Therefore, the value of 355 Btu $ft^{-2}h^{-1}$ is recommended as the peak radiation in the desert on a horizontal surface. The proportions of radiation in other than peak hours are taken from Table 1 for Yuma to give the hourly radiation in Table 2.

1.1.3 WITHSTANDING (Gringorten and Sissenwine[11])

Although not expected to operate in temperatures over 120°F, equipment should withstand, without damage, more unusual temperature extremes found in the world's hot deserts.

The record for Death Valley was assumed typical of extremely hot deserts and was used to specify the higher temperatures for this design philosophy. The highest temperature in each of 57 years from 1911 to 1968 (one year incomplete) was obtained and the distribution of these figures fitted the Gumbel distribution very well.* This permitted estimates of the 1, 10, 25, and 50 percent withstanding high temperature extremes for various expected durations of equipment exposure (EDE), Table 3.

In addition to the 10 percent probable values for standardization included in Table 3, typical diurnal cycles associated with these extremes for each EDE are needed.

The 59 year record for Death Valley, California, was searched for the maximum and minimum temperature for each day that the maximum reached or exceeded 120°F. This study showed that the minimum temperature is close to 91°F whenever the maximum temperature equals or exceeds 120°F. Hence, the associated minimum is assumed to be 91°F and the diurnal amplitudes for the 10 percent withstanding temperature extremes for EDE's of 2 to 25 years are:

EDE(yr)	Maximum Temperature (°F)	Diurnal Amplitude (F°)
2	128	37
5	130	39
10	131	40
25	133	42

Assuming, as in the Yuma statistics (see Section 1.1.2.2) that the minimum occurs at 0600 LST and using the ratios given in Table 1, 10 percent probable withstanding cycles were calculated and are presented in Table 4. Estimates of relative humidities, windspeeds, and solar radiation values associated with these withstanding cycles, also included in Table 4, are assumed to be the same as for operational cycles.

*For a discussion of the Gumbel distribution and its use in estimating withstanding extremes, see Section 1.2.4.

Table 3. High Temperature Extremes for Withstanding

Percent Extreme	EDE (yr)				
	1	2	5	10	25
1	131°F	133°F	134°F	135°F	137°F
10	127	128	130	130	133
25	125	127	128	129	131
50	124	125	127	128	130

Table 4. Diurnal Cycles of Temperature and Other Elements for Days When the Maximum Temperature Equals or Exceeds the Withstanding 10 Percent Extreme Temperature for Various EDE's

Item	Time of Day (hr)											
	1	2	3	4	5	6	7	8	9	10	11	12
Equipment Lifetime (yrs)	Temperature (°F)											
2	97	96	96	94	92	91	92	97	105	110	115	119
5	97	96	96	94	92	91	92	97	106	112	117	120
10	97	96	96	94	92	91	92	97	106	112	117	121
25	98	96	96	94	92	91	92	98	107	113	118	122
	Other Elements											
Relative Humidity (%) (dp = 20°F)	6	7	7	8	8	8	8	6	6	5	4	4
Windspeed (mph)	6.1	6.1	6.1	6.1	6.1	6.1	6.1	6.1	6.1	9.7	9.7	9.7
Solar Radiation (Btu $ft^{-2}h^{-1}$)	0	0	0	0	0	18	85	160	231	291	330	355

Item	Time of Day (hr)											
	13	14	15	16	17	18	19	20	21	22	23	23
Equipment Lifetime (yrs)	Temperature (°F)											
2	123	126	127	128	127	125	121	113	110	106	103	101
5	125	128	129	130	129	127	122	114	111	107	104	102
10	126	129	130	131	130	128	123	115	111	108	104	102
25	128	131	131	133	132	130	125	116	112	108	105	102
	Other Elements											
Relative Humidity (%) (dp = 20°F)	3	3	3	3	3	3	3	4	5	6	6	6
Windspeed (mph)	9.7	9.7	9.7	9.7	9.7	0.7	9.7	9.7	9.7	9.7	9.7	6.1
Solar Radiation (Btu $ft^{-2}h^{-1}$)	355	330	291	231	160	85	18	0	0	0	0	0

1.2 Low Temperature

Military equipment must be designed to operate at very cold temperatures and at extremes that have a small probability of being attained, perhaps only a few hours a month. Equipment must also be designed to withstand without irreversible damage even colder extremes—temperatures attained too infrequently to be of operational importance—so that equipment will again be operable upon return of milder weather.

Extreme low temperatures result from the simultaneous occurrence of an optimum combination of several meteorological elements. Long absence of solar radiation, clear skies, and calm air are the most essential requirements, with the ultimate fall in temperature dependent upon the duration of these conditions. During such conditions, there is minimum mixing of the vertical air layers. As the ground surface loses heat through radiation, the nearest air layers are cooled and, consequently, become heavier than the layers above them. Therefore, there is little possibility of the cold air escaping by rising. Since this process continues until there is change in the circulation pattern, there can be much longer durations of cold than high temperatures which have a diurnal dependence.

1.2.1 LOWEST RECORDED (Riordan[8])

Extremely cold temperatures occur in interior high-latitude localities with clear skies, conducive to maximum terrestrial radiation, and with topographic features which afford protection from wind. Geographic areas of extreme cold are the eastern Antarctic plateau (approximately 9,000 to 12,000 ft in elevation); the central part of the Greenland Icecap (approximately 8,200 to 9,800 ft in elevation); Siberia between 63° to 68°N, and 93° to 160°E (less than 2,500 ft in elevation); and the Yukon basin of northwestern Canada and Alaska (less than 2,500 ft in elevation).

Excluding Antarctica, the generally accepted world's lowest recorded temperature is -90°F. It was recorded at Verkhoyansk (elevation, 350 ft), USSR on 5 and 7 February 1892 and at Ojmjakon (elevation, 2165 ft), USSR on 6 February 1933.

Very low winter temperatures occur in the Verkhoyansk-Ojmjakon cold zone, approximately between 63° and 68°N, and 93° and 160°E. It is an area of extreme continentality, lying near the eastern end of the world's largest land mass and blocked by mountain ranges from moderating influence of oceans. There is considerable radiational cooling because winter nights are long at high latitudes leading to the building of a semipermanent anticyclone. Of the two places, Ojmjakon is potentially the colder, being located at a higher elevation and more closed in by mountains. It is possible that the temperature there may have fallen below the value recorded; temperatures of -95°F and down to -108°F have been

claimed. Considerable controversy has arisen about the Verkhoyansk records due to problems concerning instrument corrections. There is controversy about both the Verkhoyansk and Ojmjakon records because of misleading references to incorrect values in the literature.

1.2.2 OPERATIONS

1.2.2.1 1, 5, 10, and 20 Percent Extremes (Salmela and Sissenwine[14])

Maps of 1, 2, 5, 10 and 20 percent low temperature extremes for the coldest month, based on observed hourly temperature distributions, were available for Canada. These had been augmented by hourly data over the United States and Alaska, and appear as winter design temperature charts for North America in the Handbook of Geophysics (USAF GRD[10]). Thus, only Eurasia and Greenland needed mapping for completion of the Northern Hemisphere. Study of the Southern Hemisphere was not needed as no stations there are colder than the coldest Northern Hemisphere stations except for Antarctica which is excluded from MIL-STD-210B consideration.

Several frequency distributions of temperatures for some of the coldest areas over the Northern Hemisphere were available. For North America, these distributions were based on hourly observations; but over Siberia only 6 hr observations were available for use in the distributions. Time was not sufficient to obtain hourly temperature distributions for all the cold places on a worldwide basis, or even to determine the extent of frequency distributions of hourly data available on a worldwide basis to develop such distributions.

With the available information, a first approach extended the percent hours per month of -40, -50, -60 and -70°F for the coldest month from North America to Eurasia and Greenland by assuming that areas of equal mean monthly temperature had equal percent hours per month of these temperatures. These maps could then be modified with the small number of frequency distributions available. Because inland locations will have a wider range of temperatures than the coastal areas, even in the high-latitude frozen north, such an assumption could be misleading.

In hopes of resolving this problem, it was decided to modify the utilization of mean monthly temperature with mean daily temperature range, also generally available climatological data. A statistical technique was developed with these standard data and available hourly temperature frequency distributions to infer Eurasian and Greenland cold extremes for specific probabilities.

14. Salmela, H.A., and Sissenwine, N. (1970) Estimated Frequency of Cold Temperatures Over the Northern Hemisphere, AFCRL-70-0158.

Monthly frequency distributions of hourly temperatures were available for 83 Canadian stations, mainly airports (Climatology Division, 1967; 1958). The period of record was from January 1957 to December 1966. For the coldest month, January, there were over 7000 hourly observations for each station.

For 21 stations, including most of the coldest Canadian stations, the January mean temperature and the mean daily range were extracted. The 1, 5, 10 and 20 percent low temperature extremes were determined for these same stations from the January frequency distributions.

From the available distribution of 15,000 January hourly temperature observations from 1946 to 1968 for Fairbanks, Alaska, temperature values for the same percent extremes as the Canadian stations were determined. The January mean temperature and mean daily range were also derived for this set of data.

From these data, regression equations to estimate the departure, D, in degrees Fahrenheit of each percentile value (1, 5, 10 and 20) from the monthly mean temperature as a function of the mean daily range, R, in degrees Fahrenheit were computed.

These regression equations, are of the form $D_{x\%} = aR + b$. To test the regression equations, estimates of the 1, 5, 10 and 20 percent low temperature operational extremes were computed for nine independent locations (not used to develop the regression equations) from the Canadian Summaries. The results are provided in Table 5. Winnipeg and Sept-Isles had the largest errors, ranging up to 7°F. The remaining stations all had errors 3°F or less, except Churchill which had a 4°F error for the 1 percent estimate. On the whole, these results indicated that very good estimates of the 1, 5, 10, and 20 percent extremes could be made with these regression equations. The majority of errors in the estimates shown for this small sample were on the cold side, giving some conservatism to the values. This is probably because most of the locations in Table 5 are warmer than those used to obtain the regression expressions.

These regression equations were then applied to Eurasian and Greenland stations that had enough information to permit a calculation of the station monthly mean temperature and the mean daily temperature range (needed in the regression equations to determine 1, 5, 10, and 20 percent extremes). With this information, 1, 5, 10, and 20 percent low temperature operational extremes were calculated for Eurasian and Greenland stations; and Northern Hemisphere maps were prepared which give percent of time (hours) of the coldest month that temperatures are estimated to be below threshold values of -40, -50, -60, and -70°F. These maps are Figures 5 through 8.

Table 5. Estimated and Actual Cold Temperature Extremes for January

	Lat (^oN)	Long (^oW)	Alt (ft)	1% E*	1% A*	5% E*	5% A*	10% E*	10% A*	20% E*	20% A*
Montreal	45	74	98	-17	-16	-10	- 8	- 6	- 3	0	2
Sept-Isles	50	66	54	-31	-26	-23	-17	-18	-12	-10	- 6
Goose Bay	53	60	46	-27	-28	-20	-21	-16	-17	-10	-12
Winnepeg	50	97	786	-40	-33	-32	-26	-26	-22	-18	-16
Calgary	51	114	3540	-27	-26	-18	-20	-12	-13	- 3	- 4
Wiarton	45	81	720	- 6	- 6	0	2	3	5	7	10
London	43	81	912	- 9	- 7	- 3	0	1	4	6	9
Churchill	59	94	30	-45	-41	-40	-37	-36	-34	-31	-29
Knob Lake	55	67	1681	-42	-40	-35	-33	-31	-29	-23	-25
Mean Error				2.6		3.0		2.7		2.3	
RMS				3.3		3.4		3.1		2.5	

Notes:

*E - Estimated Temperature

*A - Actual Temperature

Figure 5 shows that for a threshold value of -40°F much of North America north of 50° latitude is below this value at least 1 percent of the time (hours) in the coldest month, usually January, and with a lower probability during the other winter months. Deeper into the continent there will be a large area of inoperativeness more than 10 percent of the time (hours). Most of interior Asia north of 50° latitude would be below this limit 20 percent of the time (hours) and a large area 50 percent of the time (hours). (The average January temperature in that area is well below -40°F.) Hardly any of Europe gets this cold with an appreciable frequency.

For a threshold temperature of -50°F, Figure 6 shows an inoperativeness of 1 percent of the time (hours) or greater for a small portion of North America (mainly the interior of Alaska and the Yukon Territory bordering interior Alaska), and 10 percent of the time over about one-seventh of the area of Alaska. Temperatures will be below -50°F for about half the month (50 percent of the time) along certain valleys of Siberia and over a much larger area in Siberia about 10 percent of the time (hours).

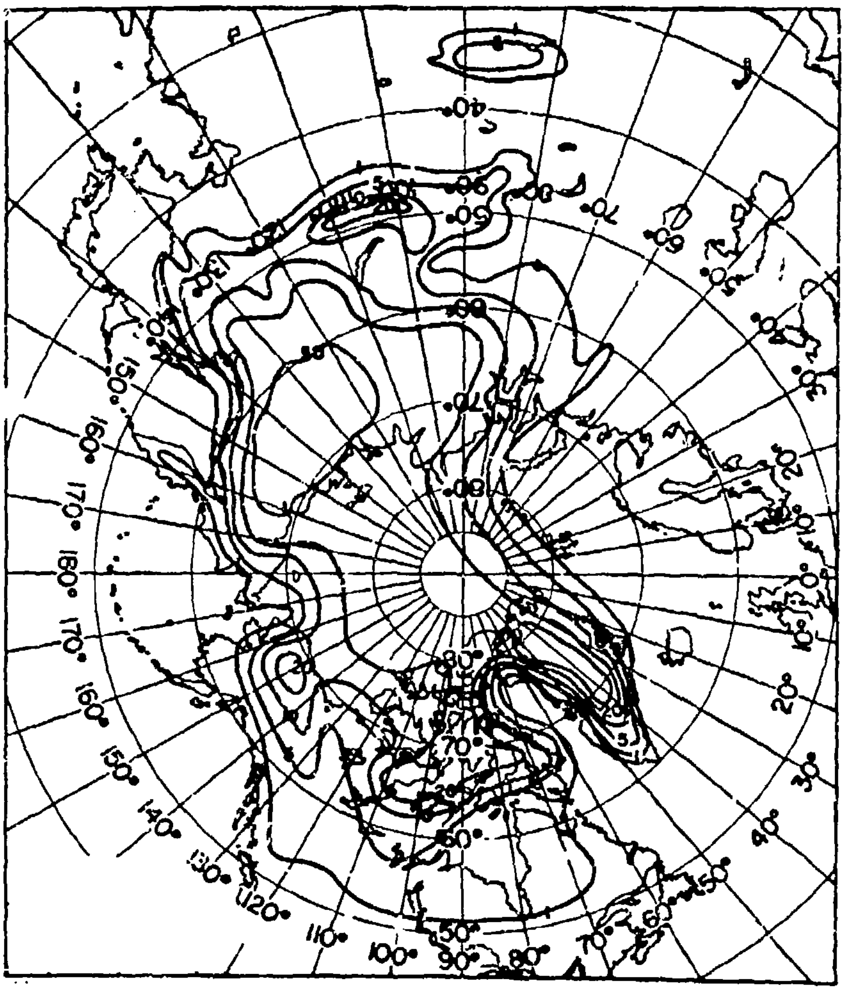

Figure 5. Northern Hemisphere Map of Estimated Percent of Hours of Coldest Month of Temperature Below -40°F

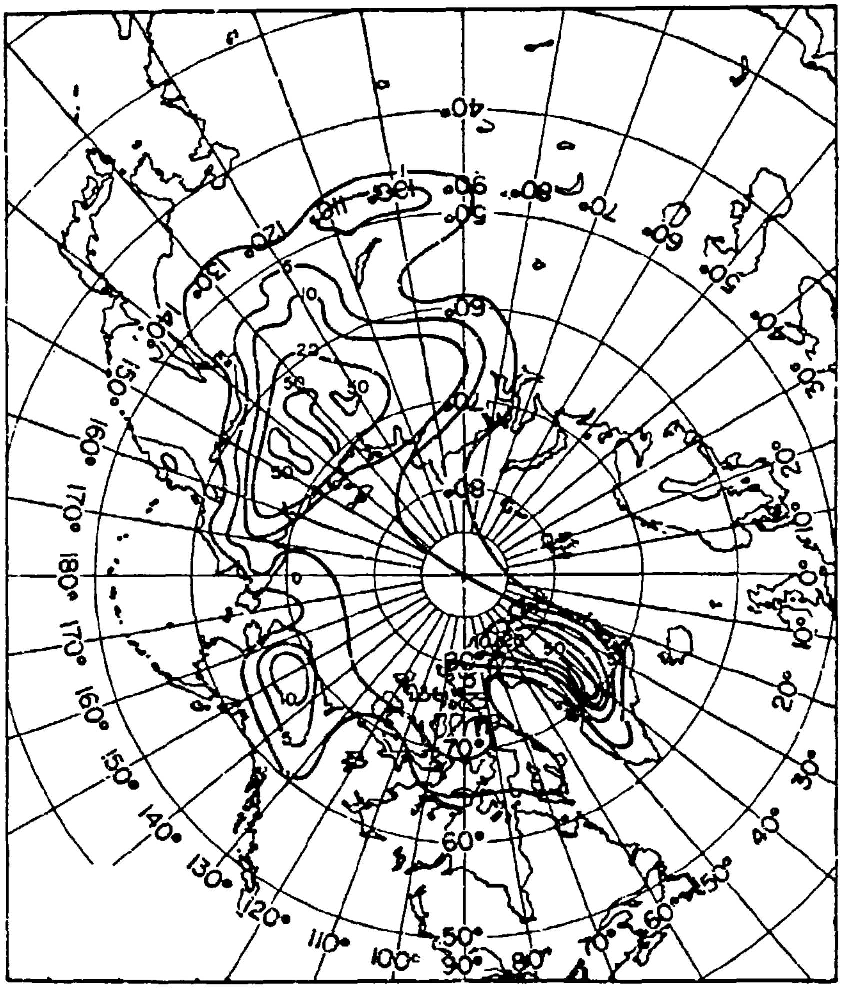

Figure 6. Northern Hemisphere Map of Estimated Percent of Hours of Coldest Month of Temperature Below -50°F

Figure 7, threshold temperature of -60°F, shows two small areas of Siberia experiencing colder temperatures 20 percent of the time (hours). This temperature was chosen as the low temperature operational design criteria for MIL-STD-210B. See Appendix A for discussion related to this choice.

For a threshold temperature of -70°F, Figure 8 depicts an area in Siberia having temperatures below -70°F 5 percent of the time (hours) and an area in Greenland having such temperatures 10 percent of the time.

Maps to depict the 1 percent low temperature extreme were not prepared by Salmela and Sissenwine[14] since such an extreme would be found in only a few areas within the cold pockets evident in Figure 8. The 1 percent extreme was determined (by the authors of this synopsis) by taking the 50 percent extreme temperature of -50°F, the 20 percent of -60°F, the 10 percent of -65°F, and the 5 percent of -70°F as deduced from Figures 5 through 8 from the interior of Siberia (the most extreme area excluding the Greenland plateau). Plotting these numbers on probability paper and extrapolating to 1 percent yields -78°F.

Since this study of cold temperature extremes has been limited to the coldest month, the number of hours of inoperability for a given percent extreme during other months, the winter season and the entire year, will be smaller. For inland stations, the number of hours of inoperability for other than the coldest months will be very much lower. As an example, consider Watson Lake (60°N, 129°W) where temperatures fall below -50°F on 3.68 percent of the hours in January but only 1.03 percent in December and 0.000002 percent in February. Minus 50°F occurs 1.63 percent of the hours of winter (December, January and February) and 0.42 percent of the hours of the year (all during the coldest four months). At maritime stations experiencing such exceptionally low temperatures (those in the very far north), percent hours inoperability will be spread out more through the year. At Isachsen (79°N, 104°W), -50°F is reached 1.29 percent of the hours in December, 4.40 percent in January, 3.79 percent in February, 3.16 percent of winter and 0.84 percent of the year.

1.2.2.2 Duration of Cold Temperatures (Gringorten[15])

The ability of equipment to operate in a cold extreme is very dependent on the duration of the extreme and the time history of temperatures surrounding this extreme. The direct approach to estimate duration would require an abundance of hourly data when cold extremes are observed. Since such information was not available, an estimate of duration was determined using a statistical duration

15. Gringorten, I.I. (1970) Duration and Unusual Extremes of Cold, AFCRL-70-0361, ERP 326.

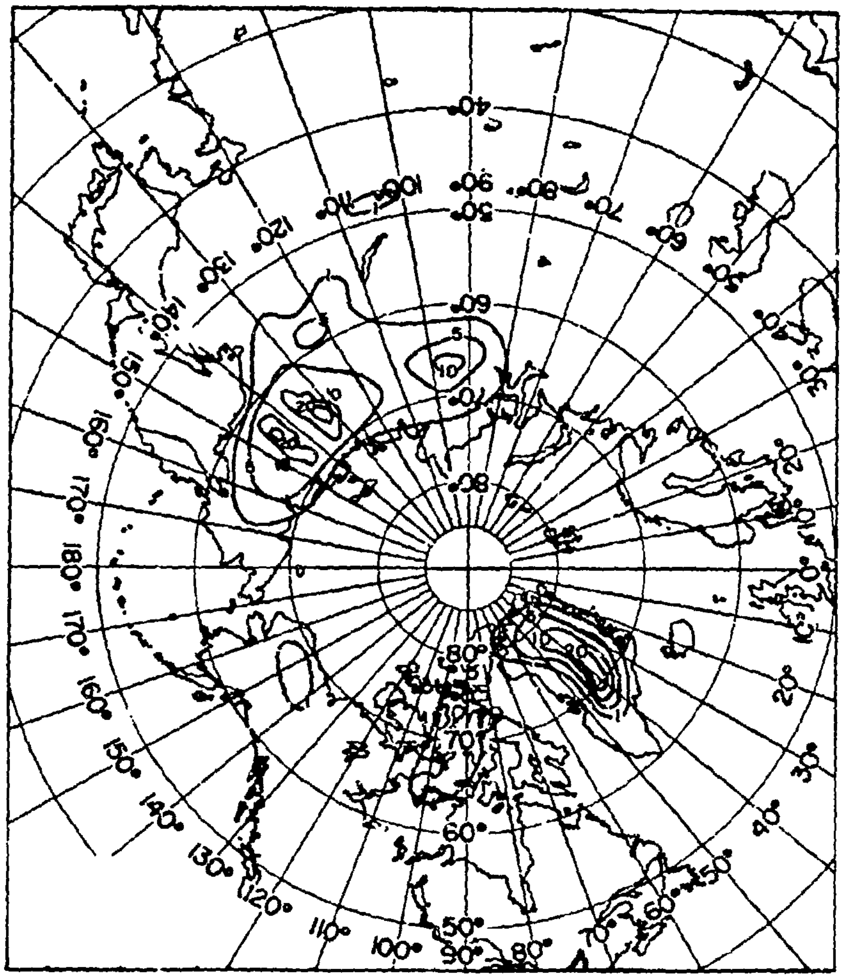

Figure 7. Northern Hemisphere Map of Estimated Percent of Hours of Coldest Month of Temperature Below -60°F

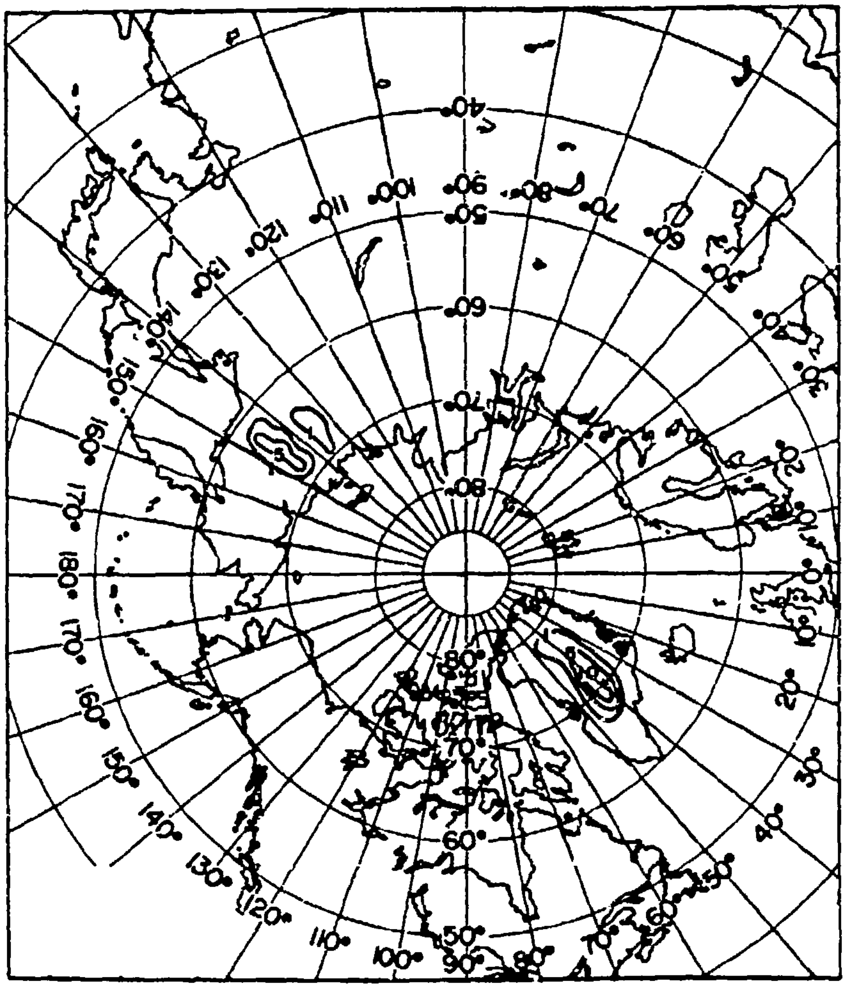

Figure 8. Northern Hemisphere Map of Estimated Percent of Hours of Coldest Month of Temperature Below -70°F

model develcped by Gringorten.[16] The model gives the probability of temperature (T) remaining continuously below T for duration of m hours, assuming a Markov* process without a diurnal cycle of temperature.

Incomplete and occasionally inconsistent hourly temperature records (1948-1963) were available for Verkhoyansk (Siberia), the station holding the North American low temperature record of -90°F. These records were useful in showing that the Gringorten duration (hours) model (using an hour-to-hour temperature correlation of 0.989 developed from a study of Snag Yukon Territory) was applicable to the Verkhoyansk temperatures.

After this determination, the model was applied to the better, though fewer and non-hourly, Verkhoyansk statistics available from the British Air Ministry.[17] These temperature statistics consisted of the daily average maximum and minimum, monthly and annual average maximum and minimum, and monthly and annual absolute maximum and minimum for the periods 1884 to 1920 and 1926 to 1935.

From such data, for the coldest month, January, it was possible to restore the cumulative hourly frequency distribution of temperatures using the Markov-type model.

From the application of the Gringorten model to this distribution and for 20 percent risk, the durations of temperatures associated with the -60°F operational extreme can be obtained from information given in Gringorten[15]; these are given in Table 6.

Under these conditions, one can assume no solar radiation and calm winds.

It can thus be seen that in areas having a 20 percent low temperature extreme of -60°F, the average temperature for durations up to 768 hours (32 days) is in itself close to -60°F. Therefore, equipment should be designed to be operable when cold soaked at -60°F.

1.2.3 WITHSTANDING (Gringorten[15])

Withstanding extremes are expected to occur in the Siberian cold centers which have the highest probability of the operational extremes. The values for withstanding should, therefore, be obtained from a record of annual extremes

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* A stochastic process wherein the probable value of ... temperature at some future time depends only on the present temperature.

16. Gringorten, I.I. (1968) Estimates of duration of a continuous variable by Markov Process, Proceedings of the First Statistical Meteorological Conference 27-29, May 1968, Hartford, Conn., Amer. Meteorol. Soc., Boston, Massachusetts, pp. 52-60.

17. British Air Ministry (1958) Tables of Temperature, Relative Humidity and Precipitation for the World, Parts I-VI, Meteorological Office, London.

Table 6. Durations of Cold Temperatures Associated With the -60°F Extreme. Each temperature in this table is the maximum, average, or the minimum in an operational time exposure of m hours, with 20 percent probability, during January, Siberian cold center

	Time m(hr)									
	1	3	6	12	24	48	96	192	384	768
Maximum Temperature	-60°F -51°C	-58 -50	-57 -49	-55 -48	-53 -47	-49 -45	-45 -43	-38 -39	-31 -35	-25 -32
Average Temperature	-60°F -51°C	-60 -51	-60 -51	-60 -51	-60 -51	-60 -51	-59 -51	-58 -50	-58 -50	-57 -49
Minimum Temperature	-61°F -52°C	-62 -52	-64 -53	-65 -54	-68 -56	-70 -57	-73 -58	-76 -60	-79 -62	-82 -63

for many decades from these areas and the Gumbel statistical model for extreme values (see Section I. 2.4). Unfortunately, data for many decades is not available from stations in Siberia having unusually cold temperatures.

In Section II. 1.2.2.2, mention is made of the data available for Verkhoyansk for the period 1884-1920 and 1926-1935. These data yielded, however, only two points for the probability versus extreme temperature distribution.

Data for Ojmjakon, for the period 1948 to 1963, were also available. These data contain 16 years of annual extremes, thus permitting 16 points on the plot of probability versus extreme temperatures. This plot shows that the data fit the Gumbel distribution well.

Using the Gumbel statistical model on the Verkhoyansk and Ojmjakon distributions, the withstanding (10 percent) low temperature extremes listed in Table 7 were obtained for the indicated EDE's.

Since values from the two separate stations and data records are in good agreement, the average (rounded to the next highest) temperatures are recommended as withstanding (10 percent) low temperature extremes. These are listed in Table 8.

The duration of withstanding extremes was estimated with the application of the model mentioned in Section II. 1.2.2.2 as having been used to determine the duration of operational extremes. This application was after the model had been tested and judged suitable for this purpose. Table 9 gives the recommended durations of withstanding extremes for various planned lifetimes.

Under these conditions one can assume no solar radiation and calm winds. For constructing a cycle, the temperatures in Table 9 can be assumed to occur at plus and minus the duration times divided by 2.

Table 7. Cold Temperatures With 10 Percent Risk

	EDE (yr)			
	2	5	10	25
Ojmjakon	-86°F	-89°F	-92°F	-96°F
Verkhoyansk	-86°F	-89°F	-91°F	-93°F

Table 8. Recommended Cold Temperature Extremes for Withstanding

	EDE (yr)			
	2	5	10	25
Temperature (10%)	-86°F	-89°F	-92°F	-95°F

Table 9. Duratio.1s of Cold Temperatures Associated With Low Temperature Withstanding Extremes

	EDE (yr)			
Duration	2	5	10	25
1 hr	-86°F	-89°F	-92°F	-95°F
12 hr	-85	-88	-89	-90
24 hr	-84	-87	-88	-89
2 days	-81	-84	-85	-87
4 days	-75	-79	-81	-82
8 days	-67	-71	-73	-76
16 days	-56	-60	-63	-67
32 days	-43	-49	-53	-57

2. HUMIDITY (Sissenwine[18])

The humidity environments, which military equipment must withstand without irreversible damage and the maximum humidity in which equipment must operate, are problems faced by designers who must think in terms of worldwide operations and withstanding.

Confusion exists in specifying humidity limits because of the number of ways in which humidity is expressed. There are two major breakdowns in the nomenclature of humidity; absolute humidity and relative humidity. Each must generally be treated separately with respect to the effect it has on the design of equipment.

Absolute humidity, the mass of water vapor in a specified volume of air, is of primary concern in the operation of equipment. Relative humidity, the ratio (expressed as a percent) of the amount of water vapor in the air to the amount that would constitute saturation, is usually related to the withstanding problem.

Relative humidity is the more common expression, but its use can be misleading and cause confusion. A given relative humidity has a far different meaning on a warm day than on a cool day because the amount of water vapor which can be present in the atmosphere increases with temperature. For example, an 80 percent relative humidity at 90°F represents an absolute humidity of 20.5 grams of water per m^3, whereas at 40°F it represents only 5.4 grams of water vapor per m^3. In the first case, an RH of 80 percent at 90°F represents a high absolute humidity. In the second case, an RH of 80 percent at 40°F represents only a moderate absolute humidity. It is apparent that relative humidity is an incomplete expression of water vapor present, and therefore should be used with caution.

2.1 Absolute Humidity

Absolute humidity is generally specified in grains/ft^3, or grams/m^3. A number of other terms may be used as alternatives to designate absolute humidity, that have a "one to one" relationship with each other. The most important of these are dew point, the temperature at which condensation would take place if the air were cooled at constant pressure, and vapor pressure, the portion of the atmospheric pressure which is due to its water vapor content. Specific humidity, the mass of water vapor per unit mass of moist air, and

18. Sissenwine, N. (1953) Maximum Humidity in Engineering Design, AFCRL-53-61, Air Force Surveys in Geophysics, No. 49.

mixing ratio, the mass of water vapor per unit mass of dry air, are also useful engineering quantities.

The chief effect of absolute humidity on design concerns the operation of equipment which, incidental to its function, or perhaps as its major function, condenses water vapor out of the air or evaporates water into the air. An ordinary refrigerator does the former, detrimental to its chief function. This results in bothersome defrosting. Carburetor icing is another example and requires a special heater in aircraft for preventive purposes.

Absolute humidity has a slight effect on the operation of high voltage electrical equipment, because the flashover voltages required for air gaps will be increased when the absolute humidity is high and decreased when the absolute humidity is low.

Absolute humidity must also be considered in design of a device which must operate during or following a transfer from a cold to a warmer environment, since condensation or frost may result if the temperature of the device is lower than the dew point equivalent of the absolute humidity of the warm air. Conversely, an object which can trap air may be similarly affected when moved suddenly into a cold environment, because the moisture contained in this air will condense when the temperature falls below the dew point and will freeze if this temperature is below freezing.

The amount of water vapor that the air may hold (the maximum absolute humidity possible) roughly doubles for each 18°F temperature increase at typical temperate climatic conditions. The source of this water vapor is the large bodies of water (oceans, seas, and large lakes). Rivers and ponds have only a very local influence. These large bodies of water use the heat received from the sun to vaporize their surface water. The absolute humidity over the water in these source regions is limited to that which corresponds to a dew point equal to the temperature of the surface water. In fact, because of upward diffusion, the dew point a few feet above water will invariably be a few degrees lower than the water temperature.

Absolute humidity decreases with horizontal and vertical distance of the air mass from its source of water, due to condensation and diffusion. It is also limited aloft by the cooler temperatures which will not support large amounts of vapor. Even within clouds the absolute humidity will be far less than that possible at the surface. It will correspond to the temperature of the water droplets (or ice particles) in the cloud in the same manner that the absolute humidity over a water body is related to the surface temperature of the water.

2.1.1 HIGH ABSOLUTE HUMIDITY

2.1.1.1 Highest Recorded (Salmela and Grantham[19])

The highest accepted absolute humidity observation (Salmela and Grantham[19]) is a dew point of 34°C (93.2°F), recorded in July at Sharjah, Arabia located on the western shore of the Persian Gulf.

Khanpur, Pakistan once reported a dew point of 36°C (96.8°F). This value was not accepted as highest recorded for two reasons. Neither Khanpur nor any other known location has ever observed a 35°C dew point. Khanpur is not located near an extensive warm water source; it is located 10 miles from the Thar desert, about 300 nautical miles northeast of the Arabian Sea in the Indus River valley. It is about 20 nautical miles from the main river, and has only one or two small tributaries and a canal in close proximity.

Gringorten et al[20] in an analysis of dew points in these regions show a tongue of moisture extending from the Bay of Bengal across Northern India into West Pakistan. However, the 5 percent high dew points in this tongue are less than those around the Persian Gulf, indicating that the highest dew points most probably do not occur at Khanpur, but in the Persian Gulf.

2.1.1.2 Operations—1 Percent Extreme and Daily Cycle (Salmela and Grantham[19])

The humidity extremes and cycle presented in this section correspond to a coastal desert environment. Extremes from such a unique environment were recommended for inclusion in MIL-STD-210B (see Appendix A).

Grantham and Sissenwine[21] suggested Sharjah, Arabia as having the world's highest 1 percent high dew point, 33.6°C (92.5°F). This extreme was based on 88 once-daily, 1200 GMT observations during the month of July for the years 1949 to 1953. However, it was later noted that 1200 GMT (1600 local time) is near the time of maximum dew point in the diurnal humidity cycle for Sharjah (Watt[22]). Consequently, this 33.6°C, 1 percent high dew point was rejected. Also rejected, after much consideration, was a 1 percent dew point of 31.7°C (89.1°F) from Khanpur, West Pakistan based on 620 July observations taken twice daily, 0300 and 1200 GMT (0800 and 1700 LST), over the 10 year period 1954 to 1963. In

19. Salmela, H., and Grantham, D.D. (1972) Diurnal Cycles of High Absolute Humidity at the Earth's Surface, AFCRL-72-0587, ERP 416.

20. Gringorten, I.I., Salmela, H.A., Solomon, I., and Sharp, J. (1966) Atmospheric Humidity Atlas - Northern Hemisphere, AFCRL-66-621, Air Force Surveys in Geophysics No. 186.

21. Grantham, D.D., and Sissenwine, N. (1970) High Humidity Extremes in the Upper Air, AFCRL-70-0563, ERP 333.

22. Watt, G.A. (1968) A comparison of effective temperatures at Bahrain and Sharjah, Meteorol. Mag. 97(No. 1155):310-313.

addition to the factors outlined in Section 2.1.1.1, the 1 percent dew point from Khanpur was rejected because, like Sharjah, it was biased to a high value since the observations were taken at 0800 and 1700 LST.

A more representative 1 percent high absolute humidity extreme is a dew point of 31°C (88°F) based on 2722 hourly observations taken 24 hours a day at Abadan, Iran. Abadan's 1, 5, and 10 percent high dew points are 88, 82 and 79°F, only about 1°F lower than those for Khanpur. Abadan is located on the northern tip of the Persian Gulf and is surrounded by marsh lands; the water in these marshes, already warm because of the influence of the Gulf, can be further heated diurnally by the sun to provide extremely high dew points.

Although Abadan has the highest 1 percent extreme, extremes for higher percents are not found in locations like Abadan where there is a wide range of the humidity regimes, but rather in the regions where the dew points are somewhat lower but more nearly constant. The 5, 10 and 20 percent dew point extremes are 30°C (86°F), 29°C (84°F) and 28°C (83°F), respectively, as determined from Belize, British Honduras data.

A survey of the days in which Abadan's dew points exceeded 84°F, an arbitrary high value near the 1 percent extreme, showed two types of temperature/dew point diurnal cycles. The first type is a nearly constant dew point throughout the day accompanied by temperatures which have a broad maximum and with winds that are either light and variable or light to moderate onshore flow. The second type is that characterized by a widely fluctuating dew point cycle ranging from the upper 60's to the middle 80's (°F). The temperature has a higher, sharper maximum than in the first type, generally reaching between 110 and 115°F. Winds in this regime are offshore at moderate speeds, 15 to 20 knots.

The first type, a constant, high dew point cycle, is the more severe for most equipment and is used for the operational cycle. The two consecutive days, 25 and 26 July 1953 shown in Figure 9, are typical of this temperature and dew point cycle. The temperature ranges between 87 and 105°F and the dew points between 85 and 91°F.

Using Figure 9 as a guide, a synthetic cycle associated with the 1 percent dew point extreme was constructed and is given in Figure 10 and Table 10. It shows the 1 percent dew point of 88°F persisting for 7 hr (roughly 1 percent of the hours in a month), and a dew point of 84°F or higher for the full 24 hr cycle. Also shown in Table 10 are the associated insolation and relative humidity cycles.

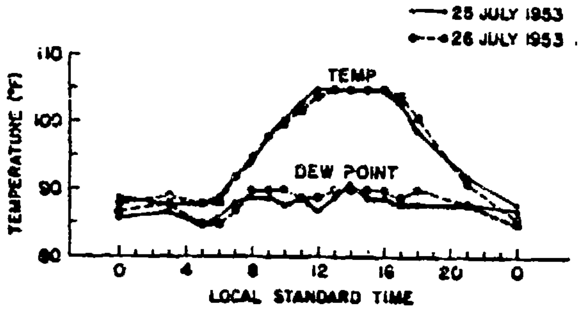

Figure 9. Daily Temperature and Dew Point Cycle for Abadan, Iran, 25 and 26 July 1953

Figure 10. Diurnal Cycle of Dew Point, Temperature, and Relative Humidity Associated With the 1 Percent High Absolute Humidity Operational Extreme (A Dew Point of 88°F in a Coastal Desert Location)

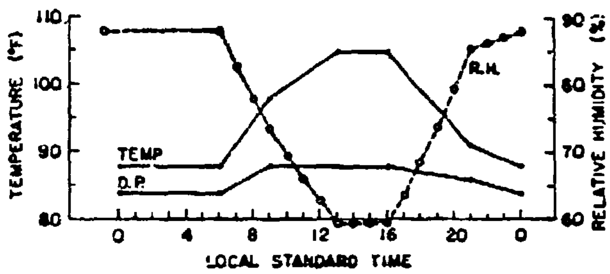

Table 10. Diurnal Cycle of Dew Point, Temperature, Relative Humidity, and Solar Insolation Associated With the 1 Percent High Absolute Humidity Operational Extreme (a Dew Point of 88°F in a Coastal Desert Location).

Time (LST)	Dew Point (°F)	Temperature (°F)	Relative Humidity (%)	Insolation* Btu $ft^{-2}h^{-1}$
0000-0500	84	88	88	0
0600	84	88	88	15
0700	(linear	(linear	83	100
0800	increase to)	increase to)	78	177
0900	88	98	73	251
1000	88	(linear	70	302
1100	88	increase)	65	328
1200	85	to	63	343
1300	88	105	60	317
1400	88	105	60	280
1500	88	105	60	225
1600	88	105	60	147
1700	(	(	64	66
1800	linear	linear	69	4
1900	decrease to	decrease to	74	0
2000	)	)	79	0
2100	86	91	85	0
2200	(linear	(linear	86	0
2300	decrease to)	decrease to)	87	0
0000	84	88	88	0

*Solar radiation values from "Port High Relative Humidity Cycle—Clear Skies" (Crutcher et al[7])

2.1.1.3 Withstanding

The general MIL-STD-210B philosophy for withstanding extremes for most meteorological elements, has been to determine the extreme expected to occur with a 10 percent risk within the expected duration of exposure (EDE) of the equipment being designed. Withstanding extremes for absolute humidity, however, present a different problem; that is, a one-time, short-duration occurrence of a dew point (which is physically limited to being at most only a few degrees higher than the 1 percent operational dew point) may not have the detrimental effect on equipment that a somewhat lower dew point occurring for an extended period of time. For this reason, the usual manner of determining withstanding extremes is not followed for high absolute humidity. Rather the withstanding extreme will be repetition of a daily cycle, typical of a location experiencing high absolute humidities for extended periods of time. Though this location will not experience the high 1 percent operational extreme typical of the coastal desert, it will experience longer periods of sustained high dew points only slightly lower than the 1 percent operational extreme.

It was thought that the cycle typical of an extended period of extreme humidity found at Dharan, Arabia for the 30 days between 21 July to 19 August 1957(when 1 percent of the hours, dew points were above 87°F, 10 percent above 84°F and 20 percent above 83°F would suffice. However, when the 30-day period was averaged by hour of the day, no hour exceeded an 80°F dew point. Even considering medians of the hourly values, only for two hours, 2200 and 2300 LST, did the median dew point reach as high as 81.5°F. This example only amplifies the fact that the areas having the extremely high dew points for shorter periods of time are not necessarily the same areas where equipments will have to withstand prolonged periods of sustained high dew points.

Long periods with high sustained absolute humidities were found at Belize, British Honduras during the month of August. For the years 1953 and 1954, the average daily temperature and dew point cycle for August (based on six-hourly data) is shown in Figure 11. The August, 1953 period was synthesized to produce the High Absolute Humidity Cycle for Withstanding in Table 11 and shown in Figure 12. The dew points in this cycle range between 79 and 83°F, and temperatures between 81 and 86°F. Such conditions are found in coastal, moist tropical locations and are approximately duplicated for a month. Adjacent months will experience only slightly less humid extremes.

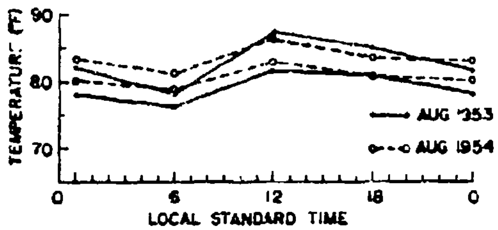

Figure 11. Average Monthly Dew Point and Temperature Cycle for Belize, British Honduras, August 1953 and 1954

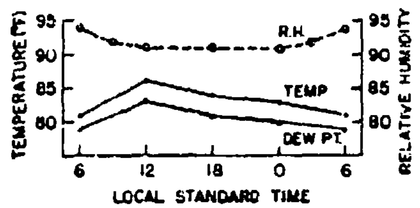

Figure 12. High Absolute Humidity Withstanding Extreme Cycle

Table 11. High Absolute Humidity Withstanding Extreme: A Dew Point and Temperature Cycle to be Repeated 30 Times

Time (LST)	Dew Point (°F)	Temperature (°F)	Relative Humidity (%)	Insolation* (Btu $ft^{-2} h^{-1}$)
0000	80.0	83.0	91	0
0300	79.5	82.0	92	0
0600	79.0	81.0	94	15
0900	81.0	83.5	92	200
1200	83.0	86.0	91	307
1500	82.0	85.0	91	252
1800	81.0	84.0	91	73
2100	80.5	83.5	91	0

Note:

Interpolate linearly between listed times.

*Solar radiation cycle estimated by using Moon[23] for moist tropics.

23. Moon, Parry (1940) Proposed standard radiation curves for engineering use, J. of Franklin Inst. 230.

2.1.2 LOW ABSOLUTE HUMIDITY

Since as shown earlier, the amount of water vapor that can be contained in air is directly proportional to air temperature, lowest absolute humidities will be found with lowest air temperatures.

Standard psychrometers with which absolute humidity is usually measured do not operate at extremely cold temperatures. However, saturation at such temperatures constitute an upper bound for low absolute humidity extremes. For the low absolute humidity extremes, the dew points associated with the lowest recorded temperatures, and 1 percent operational and 10 percent withstanding temperatures, at 90 percent relative humidity are assumed.

2.1.2.1 Lowest Recorded

The absolute humidity associated with the low temperature extreme given in Section II.1.2.1 and 90 percent relative humidity is assumed. This corresponds to a frost point of -91°F.

2.1.2.2 Operations

The absolute humidities associated with the 1 percent low temperature extreme given in Section II.1.2.2 and 90 percent relative humidity is assumed. For the 1 percent low temperature of -78°F, this corresponds to a frost point of -79°F.

2.1.2.3 Withstanding

The absolute humidities associated with the low temperature extremes and associated temperature histories given in Section II.1.2.3 and 90 percent relative humidity are assumed. For EDE's of 2, 5, 10, and 25 years, this corresponds to frost points of -87°F, -90°F, -93°F, and -96°F respective

2.2 Relative Humidity

Relative humidity is an indicator of the degree of saturation. It can be calculated by the ratio of the actual absolute humidity at a temperature to the absolute humidity required for saturation at that temperature.

The chief design problem caused by relative humidity is corrosion of metals due to oxidation and rotting of organic material due to fungi. Microorganisms are active even at 40°F when the relative humidity exceeds 80 percent. They will remain active even with a relative humidity as low as 40 percent at 80°F, and thrive at 80 to 90°F with 90 to 100 percent humidities.

High relative humidities also cause many organic materials to swell and lose shape. Degreased human hairs, for example, lengthen with increased relative humidity and are used in hygrometers for this reason. This effect cannot be

correlated with absolute humidity. Corrosion on metals and etching of ceramics is most important when the relative humidity exceeds 30 percent and the temperature approaches 80 to 90°F.

The above examples of deterioration by high relative humidity are generally a withstanding problem. However, there is very realistic operational problem, high voltage breakdown and leakage along insulators, a problem of automobile owners in humid weather and equally annoying to electronic equipment operators. This difficulty, resulting in hard starting or electronic component malfunction, is a result of the relative humidity reaching 100 percent with consequent condensation, and short circuits of the electrical components due to the increased surface conductivity. Sometimes this occurs at relative humidities of slightly less than 100 percent due to collection of water by hygroscopic dust and dirt (condensation nuclei) on these electrical parts.

The maximum relative humidity generally possible (no supersaturation), 100 percent, is encountered in nature at all temperatures up to 85 and 90°F right over water surfaces adjacent to coastal deserts. Over a great area of the world and vertical depth of the atmosphere, 100 percent RH is frequently enough to be considered in the design of any equipment that may operate outdoors in temperatures up to 80°F. Humidity of 100 percent is present in a fog and in clouds, but may also be present before fog is visible.

One hundred percent relative humidity is very closely approached in the steaming hot jungle, where the degradation effect is generally at its worst because it is accompanied by high temperature where chemical processes are fastest. High relative humidity in the dry arctic winter is the rule rather than the exception, since the loss of heat by radiation during the long nights causes the temperature to drop to the dew point of the air and then gradually depresses this dew point as the water vapor sublimes into frost or ice fog. Fortunately, very low temperatures reduce the activity of microorganisms and chemical reactions of corrosion to a standstill, and the amount of water vapor available for sublimation is extremely small.

2.2.1 HIGH RELATIVE HUMIDITY

2.2.1.1 With High Temperature

2.2.1.1.1 HIGHEST RECORDED

Surface relative humidities of 100 percent with fairly high temperature such as in the moist tropics, are possible in many parts of the world and in some areas such conditions occur quite frequently. For instance, Dodd[24] lists a relative humidity of 100 percent with a temperature of 86°F at Dobochura, Papua, New Guinea.

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24. Dodd, A.V. (1969) Areal and Temporal Occurrence of High Dew Points and Associated Temperatures, TF-70-4-ES, U.S. Army Natick Laboratories, Natick, Massachusetts.

2.2.1.1.2 OPERATIONS (Dodd;[24] Department of the Army[25])

Large open areas of the tropics have high relative humidities with high temperature. These areas have been designated the open moist tropics (see Appendix A). The joint occurrence of these relative humidities and high temperatures may cause operational problems. Giving the 1 percent relative humidity for the operational extreme is meaningless for design, since the 5 percent extreme is, in many areas, as high as 100 percent. Therefore, only a cycle typical of open areas in the rainy tropics will be provided for operations.

The conditions depicted in Table 12 may be found in open moist tropical areas during any month of the year or seasonally in at least four months of the year. The diurnal cycle includes a temperature variation from 78° to 95°F, and a relative humidity variation from 74 to 100 percent. Examples of stations with such extremes are Calcutta (India), Seno (Laos), Kampot (Cambodia), Hanoi (North Vietnam), Nanking (China), Kwajalein Atoll, Paramaribo (Surinam) and Georgetown (Guyana).

Table 12. Operational High Relative Humidity With High Temperature Extreme. Twenty-four hour cycle of relative humidity, temperature, and solar insolation typical of open moist tropics

Local Time	Relative Humidity (%)	Temperature (°F)	Insolation Btu $ft^{-2}h^{-1}$
03	100	79	0
06	100	78	15
09	82	87	200
12	75	94	307
15	74	95	252
18	82	90	73
21	95	83	0
24	100	80	0

Notes:

Value of maximum in solar radiation cycle estimated by Moon[23] for moist tropics. Rest of cycle is in proportion to values in Table 2.

Linear changes between hours can be assumed.

25. Department of the Army (1969) Research, Development, Test, and Evaluation of Materiel for Extreme Climatic Conditions, Army Regulation AR70-38, 5 May 1969, Headquarters Department of the Army, Washington, D.C.

2.2.1.1.3 WITHSTANDING (Department of the Army[25])

See note on withstanding extremes for humidity given in Section 2.1.1.3.

Equipment should be designed to withstand long immersion in nearly constant high relative humidity and high temperature depicted by the daily cycle given in Table 13. Such a daily cycle is the prevailing regime in jungles under the canopy of tropical rainforests. The feature aspect of this condition is the long duration of relative humidity at and above 95 percent. In parts of the tropics and sub-tropics, these conditions may occur on several days during any month of the year (nonseasonal), and in other parts these conditions may be more prevalent in the rainy seasons, but will occur almost any time for a few days even in dry seasons.

Table 13. Typical Jungle High Relative Humidity With High Temperature Extreme for Withstanding. Such conditions may occur several days a month throughout the year

Local Time	Relative Humidity (%)	Temperature (°F)
0300	100	Nearly
0600	100	constant
0900	95	at
1200	95	75°F
1500	95	throughout
1800	95	the 24
2100	100	hours
2400	100	

Notes:

Linear changes between hours can be assumed.

Solar radiation is near zero.

2.2.1.2 With Low Temperature

2.2.1.2.1 HIGHEST RECORDED

Values of 100 percent relative humidity with the low temperature extreme given in Section II.1.2.1 are typical as sublimation will be occurring.

2.2.1.2.2 OPERATIONS

Section 2.2.1.1.2 indicates that the customary 1 percent extreme when dealing with extremes of relative humidity is meaningless. A relative humidity

up to 100 percent during cold extremes for operations provided in Section II. 1. 2. 2 is recommended for the high relative humidity with low temperature operational extremes.

2.2.1.2.3 WITHSTANDING

Section 2.2.1.1.2 pointed out that providing extremes with any percent risk is meaningless when dealing with relative humidity. A relative humidity up to 100 percent during cold extremes for withstanding given in Section II. 1. 2. 3 is recommended for the high relative humidity with low temperature withstanding extremes.

2.2.2 LOW RELATIVE HUMIDITY

2.2.2.1 With High Temperature

2.2.2.1.1 LOWEST RECORDED

Lowest relative humidities found in nature approach zero percent; such relative humidities are found in hot deserts removed from water bodies. Sissenwine et al[12] measured a humidity of 2 percent at 110°F during a 5 hr experiment over the sand dunes in Death Valley.

2.2.2.1.2 OPERATIONS

Rather than giving the customary 1 percent probable low relative humidity extreme, the relative humidity cycle associated with the high temperature cycle for operations in Table 2 is recommended.

2.2.2.1.3 WITHSTANDING

Rather than giving the customary low relative humidity with 10 percent probability in 2, 5, 10, and 25 years, the relative humidity cycle associated with the high temperature extreme for withstanding given in Table 4 is recommended.

2.2.2.2 With Low Temperature

Not available (no design problem anticipated).

3. WINDSPEED (Sissenwine et al[26])

Equipment intended for worldwide use should be designed to operate in and withstand worldwide extremes of windspeed having only a small specified chance of occurrence. Such extremes (operational and withstanding) are derived and presented in this section.

26. Sissenwine, N., Tattelman, P.I., Grantham, D.D., and Gringorten, I.I. (1973) Extreme Wind Speeds, Gustiness and Variations With Height for MIL-STD-210B, AFCRL, to be published in AFCRL Survey in Geophysics Series.

In instances where certain equipment becomes too cumbersome and costly when designed for the withstanding windspeed, it may be desirable to provide a basic design for some reasonably high speed and provide complete withstanding capability through the use of an auxiliary "tie-down" kit. This kit would be part of and always accompany the equipment; it would be used in those parts of the world where windspeeds are known to have exceeded the threshold values for which the tie-down kit is required. Such information is available from the military operational meteorological offices.

The geographical areas applicable in establishing the withstanding speed for MIL-STD-210B are not necessarily the same as those used to determine operational extremes—areas having high average daily and/or monthly windspeeds. The areas of strongest winds lie in the hurricane/typhoon belts where the average daily and monthly winds and the 1 percent wind extreme are relatively light.

Wind equipment, especially its height above the ground, and its exposure are unfortunately far from standard. The nonuniform height of wind observations poses a particular problem in determining wind extremes, because windspeeds near the ground can vary significantly with height and a complete understanding and specification of this variability is an important problem confronting meteorologists today. The reduction, for design purposes, of wind observations from known anemometer heights to a standard height of say 10 ft, is not straightforward; it is a problem that is also compounded by differences of exposure of anemometers. Even anemometers at equal heights could record significantly different windspeeds, if one is in the lee of some taller structure. The use of available formulae to reduce this wind to a standard height would be invalid, even if the exposure were known, because such formulae do not account for such effects.

If the height and exposure of anemometers were standard*, climatologists concerned with determining wind extremes for design would still be faced with considerable difficulty because a reported windspeed is a windspeed averaged** over an interval of time which is also not standard† .

*The international standard height to which few adhere, is 10 m. At most U.S. military airports, anemometers were generally moved down from hangar and tower roofs to a height of 13 ft above the runways, the nominal wing height at the time of this change in the late 1950's.

**Windspeeds are averaged so that the windspeed is representative of the scale of weather phenomena seen on the usual weather maps; this scale is called the synoptic scale. Only then are windspeed observations useful for customary weather analysis and forecasting.

† In 1947, the International Meteorological Organization established a 20-minute average for synoptic weather reports, but this standard has not been universally adopted.

At one time, counting the number of miles of wind passing the anemometer in 5 min (with a revolution counter on the anemometer) and multiplying by 12 to obtain the miles per hour was the standard U.S. Weather Bureau observation. Very good records of these 5 min winds taken on the hour or every 6 hr, including the daily extreme, were kept until shortly after World War II when more sophisticated indicating and recording anemometers—which can provide continuous records of speed averaged over periods as low as a few seconds in duration—came into use (USWB[27]).

The current standard averaging time period in the United States is 1 min. In England and Canada, a 10 min windspeed is customary when speed recorders are available, otherwise the averaging period is something over 15 sec (Shellard[28]); however, in published climatic data, hourly (60 min) averaged winds are often given.

The average or so-called "steady-wind" (especially for averaging periods on the order of minutes) reported on an hourly basis is useful for determining the operational wind extreme - the value equalled or exceeded 1 percent of the time (hours) in the windiest month at the windiest location. Gusts associated with such speeds must also be considered as part of the operational problem.

On the other hand, the withstanding extremes should be based on annual maximum steady winds and associated gusts. In this case, the chief use of the steady speed is to obtain the gust most critical for specific equipment dimensions. As in the case of the steady wind, anemometer height and exposure have a pronounced influence on gust extremes; in addition, the ability of an anemometer to adequately respond to these short-period wind fluctuations is important. The duration, or implicitly, the size of wind gusts is highly variable and thus the overall effect of a gust on a particular item will depend on the item size and shape.

The ratio of the gust speed to the steady windspeed, called the gust factor, tends to decrease as the steady windspeed increases and as the averaging interval upon which the steady wind is based, decreases. Although a host of other factors also influence this ratio, one can develop approximations for the gust factor as a function of steady windspeed.

Large tall structures such as television transmitter towers, skyscrapers, missiles (on the pad), and bridges may be damaged because of undamped elastic motions induced in these structures by periodic variations of windspeed in resonance with the natural response frequency of the structure. To provide wind

27. U.S. Weather Bureau (1963) History of Weather Bureau Wind Measurements, U.S. Dept. of Commerce, Washington, D.C.

28. Shellard, H.C. (1968) Tables of Surface Windspeed and Direction Over the United Kingdom, Meteorological Office No. 792, Her Majesty's Stationary Office, London.

design criteria for this effect, one would examine the wind/turbulence spectra from different locations/elevations. However, such structures are usually designed for a particular location and, as such, are not within the purview of MIL-STD-210. Therefore, wind spectra extremes are not presented in this section.

Unless otherwise specified, standard units of windspeed, herein, will be in knots and meters per second, at a height of 10 ft above ground (1 knot = 1.15 mph = 1.69 fps = 0.515 mps). The factors given in Table 14 should be used to convert speeds at 10 ft to windspeeds at other heights. Conversion factors are based on the power law relationship

$$\frac{S_Z}{S_{10\ ft}} = \left(\frac{Z(ft)}{10\ ft}\right)^P ,$$

where P is 0.125 for operational steady speeds and 0.080 for operational gusts, withstanding steady speeds, and gusts (Sissenwine et al[26]).

All steady speeds will be 1 min averages. Gust speeds reported in weather observations are normally considered to be about 2 sec averages, but for designing various sized equipments, other short-duration gusts are often applicable. Sherlock[29] indicates that a gust must have a duration such that its size is about eight times the downwind dimension of a structure in order to produce a force on the structure commensurate with the gust speed. For example, a structure with a 12.5-ft downwind dimension must have a 100-ft long gust to establish full dynamic pressure on the structure. Smaller structures will be sensitive to shorter-duration gusts and, for a given size structure, the faster the steady windspeeds, the shorter the gust necessary to establish the full dynamic force.

The most probable gust extremes associated with the 1-min steady extremes presented in the following sections are scaled to arbitrarily chosen downwind equipment dimensions of 2, 5, 10, 25, 50 and 100 ft. Because the placement of most equipment will not take into consideration the direction of the extreme windspeeds, the shortest horizontal dimension of the equipment should be considered the downwind dimension.

3.1 Highest Recorded (Sissenwine et al[26])

Directly recorded data for record wind extremes are very rare due to damage or destruction of the wind measuring instruments, power outages, etc., during

29. Sherlock, R.H. (1947) Gust Factors for the Design of Buildings, Int. Assn. for Bridge and Structural Engineering, pp 8, 207-235.

Table 14. Factors to Convert Windspeeds at 10 ft Above Ground to Windspeeds at Other Heights. Based on the power law relationship, $S_Z/S_{10\ ft} = (Z(ft)/10\ ft)^P$

Height ft(m)	P = 0.125*	P = 0.080**
≤ 5 (1.5)	0.917	0.946
10 (3)	1.000	1.000
20 (6)	1.090	1.057
30 (9)	1.147	1.092
40 (12)	1.189	1.117
50 (15)	1.222	1.137
75 (23)	1.286	1.175
100 (30)	1.334	1.202
125 (38)	1.371	1.224
150 (46)	1.403	1.242
200 (61)	1.454	1.271
250 (76)	1.500	1.294
300 (91)	1.530	1.313
350 (107)	1.560	1.329
400 (122)	1.586	1.343
500 (152)	1.631	1.368
600 (183)	1.668	1.388
700 (213)	1.701	1.405
800 (244)	1.729	1.420
900 (274)	1.755	1.433
1000 (305)	1.7[illegible]	1.445

Notes:

* For use with operational steady winds.

** For use with operational gusts, and with withstanding steady winds and gusts.

the event. After the passage of severe phenomenon such as tornados, typhoons, and hurricanes, there are numerous reports in the newspaper or other media of very high windspeeds, but attempts to obtain records substantiating such reports invariably indicate that the speeds were estimated. The reliability of such estimates is unknown and variable; some might be from a weather station where visually observed windspeed dials are still in operation even though the recorder lost power; others might be calculated from the amount of force required to blow over a building or tree, or to drive a metal rod through a wooden post.

The recognized worldwide maximum windspeed measured at a surface station is a 5 min speed of 204 mph (177 knots) and a 1 sec gust of 225 mph (196 knots) measured at the Mt. Washington, New Hampshire Observatory on 12 April 1934 (Pagluica et al[30]). The Mt. Washington Observatory is 6282 ft above MSL and the anemometer was mounted at 38 ft.

Mt. Fuji, Japan (elevation 12,375 ft) is also known for its windiness. In a 23 year record, a maximum 30 min windspeed of 141 knots was observed in 1942. No gust speeds were available from this location. However, since these are point type observations not representative of a general area, these values should not be considered for purposes of MIL-STD-210B.

Tornado winds also are excluded from consideration because they are considered to be too localized. No wind measuring device has ever survived the full fury of a tornadic wind. Speeds up to 120 mph have been observed, but many authorities have suggested that the winds could exceed 400 mph. (One has estimated that winds in localized regions of the funnel may reach peak speeds close to the speed of sound (Battan[31]).)

The worldwide maximum (recorded) windspeed, a 152 knot gust (height, 30 ft, corresponding to 139 knots at 10 ft) occurred during a typhoon that passed over Iwo Jima AB, Volcano Islands in 1948. The maximum sustained wind is a 5 min speed of 131 knots measured at a height of 54 ft (corresponding to 119 knots when corrected to a 1 min speed at 10 ft) at San Juan, Puerto Rico. However, a wind of this magnitude appears to be an extremely rare occurrence for San Juan. In a 69 year record, the next highest annual 5-min sustained winds were only 104, 78, 70 and 61 knots.

The two extremes cited above should not be considered as the highest winds that have occurred over a general area of region. Certainly, higher speeds have occurred; they merely have not been recorded due to their devastating damage.

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30. Pagluica, S., Mann, D.W., and Marvin, C.F. (1934) The great wind of April 11-12, 1934, on Mount Washington, N.H., and its measurement, Mo. Wea. Rev.:186-195.

31. Battan, Louis J. (1961) The Nature of Violent Storms, Doubleday and Co., Garden City, New York.

The highest windspeeds affecting sizable areas occur within the typhoons that pass over the islands of the Western North Pacific Ocean. Of these, Typhoon Nancy was the most intense typhoon ever observed by the Joint Typhoon Warning Center (inception date for the JTWC was 1945). During the peak intensity of Typhoon Nancy, there were five consecutive air reconnaissance observations during the period 0230Z, 10 September to 0630Z, 12 September 1961, each of which indicated reliable estimated maximum surface winds of 200 knots. However, the total analysis of the storm must have indicated a somewhat lesser intensity because the JTWC reported the maximum surface winds to be 185 knots from 11/1200Z to 12/0600Z (JTWC[32]).

Windspeeds, determined by aerial reconnaissance, are considered to be steady winds with averaging times corresponding to a duration of several minutes; since one of the primary methods used for estimating surface windspeeds is from the state of the sea, such as size and number of white caps, color, etc. Other methods incorporate measurements from Doppler radar and sea-level pressure measuring dropsondes. This latter technique was probably used for the 200 knot estimates cited above, since in such an intense storm low-level penetrations needed to determine the state-of-the-sea are not made.

For this documentation, it is assumed that the highest sustained windspeeds affecting a sizable area of military concern was the 185 knots (sustained for a duration of several minutes). The most probable 2 sec gust expected to accompany this sustained wind would have been 204 knots.

3.2 Operations (Sissenwine et al[26])

The location having the highest 1 percent wind extreme is Northern Scotland. Typical of the area is Stornoway where in the windiest month (December), the 1, 5 and 10 percent high windspeeds are 43, 36 and 33 knots, respectively (1 min speeds at a 10 ft height).

The most probable gust that can be expected to accompany these 1, 5 and 10 percent windspeeds are given in Table 15.

3.3 Withstanding

In addition to being able to operate under the wind conditions outlined in Section 3.2, the equipment must also withstand, without irreversible damage, the windspeed that can be expected to occur, with a 10 percent probability, during the

32. JTWC (1962) Annual Typhoon Report, 1961, U.S. Navy - Air Force Joint Typhoon Warning Center, Fleet Weather Center, Guam.

Table 15. Operational Wind Extremes—1-Min Steady Winds and Associated Gusts. All speeds are in knots (m/s) and apply to a 10-ft (3 m) height

Percent Extreme	1-min Steady	Associated Gust for Equipment of Given Shortest Horizontal Dimension, ft (m)					
		≤2(0.6)	5(1.5)	10(3)	25(8)	50(15)	100(30)
1	43(22)	62(32)	59(30)	56(29)	53(27)	50(26)	48(25)
5	36(19)	52(27)	49(25)	47(24)	44(23)	42(22)	40(21)
10	33(17)	48(25)	45(23)	43(22)	40(21)	38(20)	36(19)

estimated duration of field exposure of the equipment, at the windiest worldwide location.

The area having the highest winds in the world (excluding mountain peaks and tornado tracks) is in the typhoon belt of the North Pacific Ocean. Locations typical of the center of this belt are the Volcano Islands (for example, Iwo Jima) and Ryukyu Islands (for example, Okinawa). Of these locations, Naha, Okinawa (26°12'N, 122°30'E, station elevation 24 ft MSL) was found to have the highest annual extremes. Based on 19 years of data, the mean of the highest annual 2 sec gusts is 84 knots with a standard deviation of 26.4 knots. Applying these statistics in the theory of extremes (Gringorten[33]) the 2 sec gusts which can be expected, with a 10 percent probability for EDE's of 2, 5, 10 and 25 years are 134, 154, 167 and 188 knots respectively. The most probable 1-min steady wind associated with these 2 sec gusts are 119, 140, 156 and 176 knots respectively.

As described in the introductory section above, the withstanding criteria will be that gust which has a duration long enough to build up full dynamic force on the specific piece of equipment being designed. Based on the 1-min steady speeds given above, the withstanding gusts, scaled to the shortest horizontal dimension of the equipment, are given in Table 16. For example, a temporary shelter (10 ft × 15 ft) with a 25 year EDE would need to withstand 176 knots gusting to 196 knots.

33. Gringorten, I.I. (1963a) A simplified method of estimating extreme values from data samples, J. Appl. Mech. 2:82-89.

Table 16. Withstanding Wind Extremes*—1-Min Steady Speeds and Associated Gusts

EDE (yr)	1-min Steady Speed knots (m/s)	Gust, knots (m/s), for Shortest Horizontal Dimension, ft(m)					
		≤2(0.6)	5(1.5)	10(3)	25(8)	50(15)	100(30)
2	119(61)	149(77)	144(74)	141(73)	137(71)	134(69)	132(68)
5	140(72)	169(87)	165(85)	162(83)	158(81)	155(80)	152(78)
10	156(80)	184(95)	180(93)	177(91)	173(89)	171(88)	167(86)
25	176(91)	202(104)	198(102)	196(101)	193(99)	190(98)	187(96)

Note:

* At 10 ft above ground.

4. PRECIPITATION

Precipitation, the meteorological term for water of any form falling on the earth from clouds, may be either liquid (rain or drizzle) or frozen (snow, hail, sleet). In this section, precipitation extremes will be given for rainfall rate, blowing snow, snowload, ice accretion, and hail size.

4.1 Rainfall Rate

Rainfall rate is generally measured by the depth to which it covers a horizontal unit area of the earth's surface during a given period. Precipitation is caught in gages whose diameter represents the horizontal unit area. Size, shape, and exposure of the gage are important. Precautions need to be taken to prevent precipitation from splashing out of the gage or being blown out by wind. In hot, dry areas evaporation can be a problem. Various requirements to cover these problems have been established by the World Meteorological Organization.

Gages are of two main kinds: nonrecording, and recording. The former provides a means of collecting and measuring precipitation, and the latter incorporates mechanisms for recording the amount of fall during a short period or the rate of fall at any instant.

Even with the most efficient instruments, functioning perfectly and in the most favorable sites and exposures, there are still problems in obtaining representative precipitation values. The standard gage diameter in the United States is 8 in. Thus the horizontal unit area covered by the measured precipitation is about 50 square in. Intense rainfall is often very localized and maxima may be missed even by an observation network.

Generally, for precipitation to occur, moist air must be lifted and thereby cooled below its dew point. There are three major mechanisms by which air may be lifted: local heating, cyclonic, and orographic. Lifting by different methods results in precipitation with different characteristics and geographical distributions, as well as different kinds of record extremes. Convective (local heating) precipitation results from overturning of cooler air by warmer air from below and takes the form of heavy, localized showers, such as thundershowers. Convective showers tend to be most frequent in warm areas and seasons, and are responsible for many of the extreme short-period rainfalls.

Cyclonic precipitation results from mechanisms associated with low-pressure centers (cyclones) and with zones of convergence and lifting of different air masses (fronts). The most severe cyclonic storms, hurricanes or typhoons, bring very heavy and prolonged rain and are responsible for most of the extreme amounts that occur over a period of several hours or days. Certain parts of the world, mostly oceanic and coastal areas, lie along the tracks usually taken by these storms.

Orographic precipitation results from upward motion of air when it is forced to ascend over topographic features. This type often occurs in conjunction with convective and cyclonic types and tends to increase the amounts produced by them, the increase being greatest on steep windward slopes. Also, precipitation can increase when sharply narrowing valleys between slopes act as funnels on up-valley winds. Highlands in the path of moisture-carrying winds from warm seas have abundant and frequent precipitation; such areas have the highest average annual rainfalls. Among them are the east- and south-facing slopes of the Himalayas, the western slopes of the Andes in Colombia, and mountain ranges along the northwest coast of North America.

4.1.1 HIGHEST RECORDED (OVER DIFFERENT TIME INTERVALS) (Riordan[8])

The World's greatest recorded 1 min rainfall is 1.23 inches (31.2 mm) at Unionville, Maryland, on 4 July 1956. This extreme fall occurred during an afternoon of intense thunderstorms in the foothills of northern Virginia and adjacent north-central Maryland. At Unionville, the total precipitation during the storm was 3.60 in., of which 2.84 in. fell during a 50 min period from 1450 to 1540 Eastern Standard Time. Rainfall was measured with a recording rain gage located in a satisfactory exposure. This exceeded the previous world record 1 min rainfall of 0.69 in. at Jefferson, Iowa, which, in turn, had exceeded the earlier record of 0.65 in. at Opid's Camp, California.

The greatest rainfall from readily available records for about 1 hr is 12 in. which occurred all within a 42 min period (7.25 mm/min) at Holt, Mo. as a local intensification in a long, narrow squall line a short distance ahead of a surface cold front.

The World's greatest 12 hr rainfall is 53 in. on 28-29 February 1964 (average of 1.87 mm/min) at Belouve, La Reunion Island.

The World's greatest 24 hr rainfall is 74 in. on 15-16 March 1952 (average of 1.31 mm/min) at Cilaos, La Reunion Island.

The World's greatest five day rainfall is 152 in. on 13-18 March 1952 at Cilaos, La Reunion Island

La Reunion Island is located in the Indian Ocean at approximately 21°S, 55°30'E. It is about 30 by 40 miles in extent and very mountainous, with steep slopes and narrow valleys. Sea surface temperature is highest during the tropical cyclone season, reaching 81°F in March. The record-producing rainfall at Cilaos occurred during a tropical storm as did, presumably, that at Belouve. These storms broke the previous 24-hr world record, 45.99 in. at Baguio in the Philippines in 1911, and the Cilaos storm broke the previous five-day world record of 150 in. at Cherrapunji, India, in August 1841.

4.1.2 OPERATIONS

4.1.2.1 0.1, 0.5, and 1.0 Percent Extremes (Salmela et al[34])

Operation of equipment is affected by how hard it is raining, the instantaneous rate of rainfall. Heaviest rainfalls, often quite showery, have the highest expectancy in tropical areas, especially over windward coasts and slopes. Unfortunately, little data is available on instantaneous rates of precipitation. Total amounts, measured every 6 hr, make up the climatological records. Available short duration rate of rainfall data are mostly for temperate locations where a few research investigations have been undertaken. In order to determine operational extremes of instantaneous precipitation rates on a large scale, a technique for obtaining intensities from readily available precipitation data was developed.

Lenhard et al[35] presented the development of statistical models in the form of regression equations for estimating instantaneous precipitation intensities from available climatology. They provided relationships—considered preliminary because the data base used was limited and is being expanded—between instantaneous rainfall rate and readily available climatological parameters.

These models have enough precision to be of great value in providing estimates of heavy precipitation rates that are equalled or exceeded with fairly low monthly expectancy. For lower intensities, the standard error of estimate reduces the precision considerably.

34. Salmela, H.A., Sissenwine, N., and Lenhard, R.W. (1971) Preliminary Atlas of 1.0, 0.5, and 0.1 Percent Precipitation Intensities for Eurasia, AFCRL-71-0527, ERP 374.

35. Lenhard, R.W., Cole, A.E., and Sissenwine, N. (1971) Preliminary Models for Determining Instantaneous Precipitation Intensities From Available Climatology, AFCRL-71-0168, ERP 350.

Required for the regression equations is a precipitation index, the monthly precipitation divided by number of days per month with precipitation. This index was computed for a large number of stations over Europe, Asia and the Philippine Islands for January, April, July, and October. The study for the purposes of revising MIL-STD-210 was limited to the above areas because previous investigations had shown that the Eurasian area generally had the highest representative instantaneous rainfall rates in the world (excluding anomalous locations such as tropical mountain peaks and the unrepresentative record 1-min rates in the United States).

Although precipitation data were selected from standard climatological sources, data are not very standard. The total monthly precipitation is given in inches or its metric counterparts, millimeters or centimeters. However, the description of a day with precipitation is quite varied. For most stations a rain day is either one which had 0.1 mm (0.004 in.) or more, or a day on which 0.01 in. or more precipitation has occurred. For many of the former British colonies experiencing heavy rainfall, such as India and Burma, a rain day was one with 0.1 in. or more. There also were some for which 1.0 mm (0.04 in.) and others for which a trace was considered a rain day. Fortunately, these "trace" cases were scarce and occurred in regions of low precipitation intensities. Though the rainfall indices were not uniformly determined on account of the different definitions of the rain day, the effect on determining the rainfall rates is not serious because regression equations were developed for each definition of a rain day.

These regression equations are as follows:

For the operational 1 percent extreme rainfall rate:

(1) For stations classifying a rainy day as having at least 0.01 in. (0.25mm) or 0.004 in. (0.1 mm) of rain,
$$R = -0.001805 + 0.009745\ I;$$

(2) For stations classifying a rainy day as having at least 0.1 in. (2.5 mm) of rain,
$$R = -0.02965 + 0.007395\ I;$$

(3) For stations classifying a rainy day as having at least 0.04 in. (1.0 mm) of rain,
$$R = 0.002695 + 0.006769\ I.$$

For the operational 0.5 percent extreme rainfall rate:

(1) For stations classifying a rainy day as having at least 0.01 in. (0.25 mm) or 0.004 in. (0.1 mm) of rain,
$$R = 0.02321\ I + 0.004019\ T - 0.3450\ ;$$

(2) For stations classifying a rainy day as having at least 0.1 in. (2.5 mm) of rain,
$$R = 0.01757\ I + 0.004882\ T - 0.4324\ ;$$

(3) For stations classifying a rainy day as having at least 0.04 in. (1.0 mm) of rain,
$R = 0.01776\, I + 0.00444\, T - 0.3490.$

For the operational 0.1 percent extreme rainfall rate:

(1) For stations classifying a rainy day as having at least 0.01 in. (0.25 mm) or 0.004 in. (0.1 mm) of rain,
$R = 0.04225\, I + 0.01354\, T - 0.8548$;

(2) For stations classifying a rainy day as having at least 0.1 in. (2.5 mm) of rain,
$R = 0.03415\, I + 0.01494\, T - 1.0409$;

(3) For stations classifying a rainy day as having at least 0.04 in. (1 mm) of rain,
$R = 0.03539\, I + 0.01399\, T - 0.8858.$

The choice of percent extremes, 1.0, 0.5 and 0.1, was governed by guidance received from the Office of the Assistant Secretary of Defense (JSC[4]).

In all of these equations, I is the precipitation index and T the monthly mean temperature in degrees Fahrenheit. These equations were derived by multiple regression and so, in areas of low precipitation indices, negative rates, which are fictional, are sometimes obtained. Fortunately this only occurs in areas where, and seasons when, precipitation is very low and the true intensities for these probabilities will be so low as to be of little importance in design and operations. For rainfall rates with the lower probabilities in regions and seasons of moderate to heavy precipitation, where most interest lies, computed rates are positive and meaningful.

Using these equations, precipitation rates that are exceeded 1.0, 0.5, and 0.1 percent of the time—the 1, 0.5, and 0.1 percent extremes for midseason—were computed. These rates were plotted on charts and isolines of intensities were drawn delineating regions of low and high rate. Important features of intense rainfall rates over Europe and Asia are highlighted in Table 17. Locations, altitudes, years of record, and 0.5 and 0.1 percent extremes are given for weather stations which have either the highest rates over both continents for any of the midseason months or significantly higher rates than other stations in their respective areas.

Figure 13 shows 1 percent extreme precipitation rates for July. These values exceed intensities presented on analogous maps for January, April, and October. Cherrapunji, India, with 0.65 mm/min is the location with the greatest intensity. Burma, S.E. Cambodia, the Gulf of Tonkin and the Philippine Islands all have rates of about 0.30 mm/min. The heaviest 1 percent extreme rates over Europe and Asia are only slightly more than 0.10 mm/min occurring over Portugal, Yugoslavia and just east of the Black Sea in the Caucasus region.

Table 17. Rainfall Rates (mm/min) for Selected Stations

Station	Location		Elevation	POR	0.5 Percent Intensity				0.1 Percent Intensity			
	Lat N	Long E	(ft)	(yr)	Jan	Apr	Jul	Oct	Jan	Apr	Jul	Oct
Indochina												
Val d'Emeraude	10.6	104.1	3117	19	0.13	0.52	0.80	0.44	0.50	0.89	1.74	1.07
Tu Dung	18.2	106.1	22	9	0.16	0.08	0.69	0.83	0.48	0.16	1.56	1.83
Quang Tri	16.7	107.2	23	34	0.23	0.09	0.31	0.79	0.61	0.42	0.87	1.70
Burma												
Sandoway	18.3	94.3	36	74	-	0.55	0.99	0.31	-	1.31	2.16	0.84
Sittwe	20.1	92.9	17	60	-	0.42	0.84	0.53		1.07	1.86	1.27
India												
Cherrapunji	25.0	92.0	4309	49	0.13	0.69	1.50	0.82	0.34	1.49	3.13	1.76
Caucasus												
Batumi	41.7	41.6	10	35	0.18	0.08	0.27	0.48	0.36	0.23	0.71	1.04
Lenkoran	38.8	48.8	-62	19	0.04	0.03	0.18	0.35	0.12	0.16	0.59	0.80
Greece												
Kerkira	39.6	19.9	89	36	0.16	0.09	0.09	0.33	0.37	0.32	0.42	0.78
Turkey												
Rize	41.0	41.5	425	11	0.22	0.08	0.25	0.36	0.45	0.26	0.67	0.88
Yugoslavia												
Cetinje	42.4	18.6	2205	49	0.46	0.39	0.18	0.51	0.82	0.78	0.53	1.04

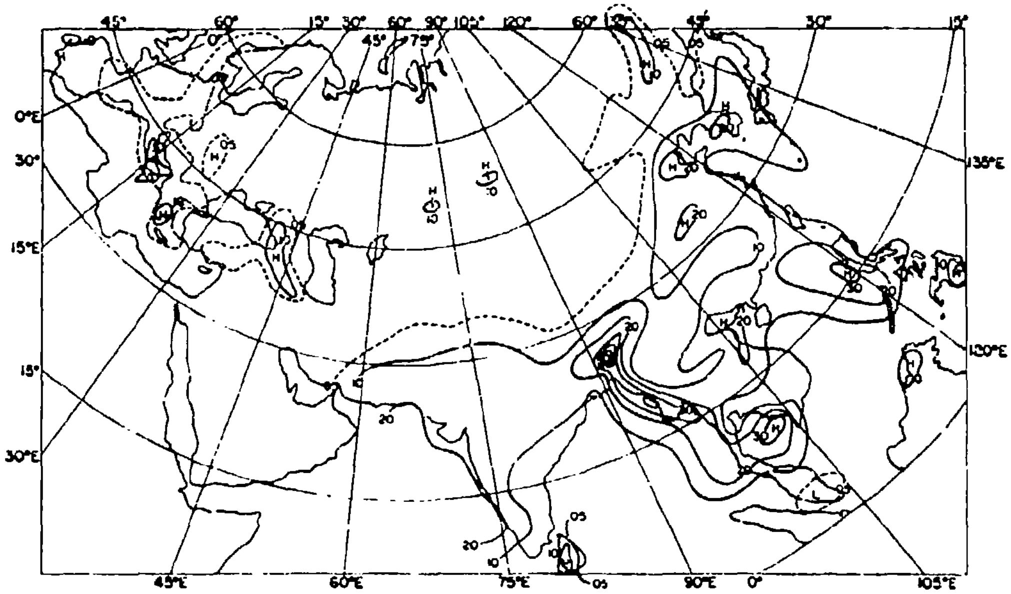

Figure 13. Rainfall Rate (mm/min) Equalled or Exceeded 1 Percent of the Time During July

Figure 14 provides estimates of 0.5 percent extreme precipitation intensities for July. The pattern is again the same as for the 1.0 percent. Cherrapunji has a rate of 1.5 mm/min (3.54 in./hr) for this percent extreme.

Figure 15 provides estimates of 0.1 percent extreme precipitation rates for July. The same features appear as in Figure 14 but in much sharper relief. The highest rate for the 0.1 percent extreme occurs over Cherrapunji in July, 3.13 mm/min (7.4 in./hr). Several stations along the Burma coast have rates of nearly 2.00 mm/min. Val d'Emeraude in S.E. Cambodia has a rate of 1.74 mm/min, and several stations along the Gulf of Tonkin reach 1.50 mm/min. The corresponding map for October, not included, have several stations along the Gulf of Tonkin with 0.1 percent extreme rates over 1.60 mm/min and one 1.88 mm/min, even higher than the Cherrapunji October rate of 1.76 mm/min. Cetinje, Yugoslavia has a strong 1.04 mm/min rate approaching the high 0.1 percent extreme rates of some of the Far East stations and very much higher than elsewhere over Europe.

The guidance provided by the Office of the Assistant Secretary of Defense (JCS[4]) suggested that equipment which is to be used anyplace in the world should be designed for the 0.5 percent extreme in the rainiest area of the world during the most severe months. Since Southeast Asia is the rainiest area of the globe, patterns in Figure 14 can serve to provide the desired values. They show an area a few degrees wide in longitude extending from about 10° to 27°N, Burma-Malaysia, in which intensities equal or exceed 0.5 mm/min (1.2 in./hr) at the 0.5 percent extreme level. One of the three centers of precipitation within this area includes Cherrapunji with three times this intensity. The area covered by this intensity is so small that it is not representative of much of the rainy tropics and thus not a logical design criteria. However, an intensity of 0.8 mm/min (1.9 in./hr) includes considerable area in Burma-Malaysia and is also found in southern Cambodia, justifying its use as a design criterion.

As mentioned in Appendix A, the Office of the Assistant Secretary of Defense (JCS[4]) also expressed concern for failure of equipment which would directly endanger human life. A typical example might be failure of the engine of an aircraft as it passed under a rain shower during takeoff. The JCS stated for such "loss of life" situations "the design criteria for climatic extremes should be established so as to result in a percentage of (time) inoperability which is as close to zero as is practically possible." Figure 15, that for 0.1 percent extreme for July, the most severe month, can be examined with this in mind. Intensities of 1.40 to 1.60 mm/min, about 3.5 in./hr, are found in about the same areas as those for the 0.5 percent worst area extreme of 0.8 mm/min intensity. The 0.1 percent value for Cherrapungi is 3.13 mm/min, 7.4 in./hr.

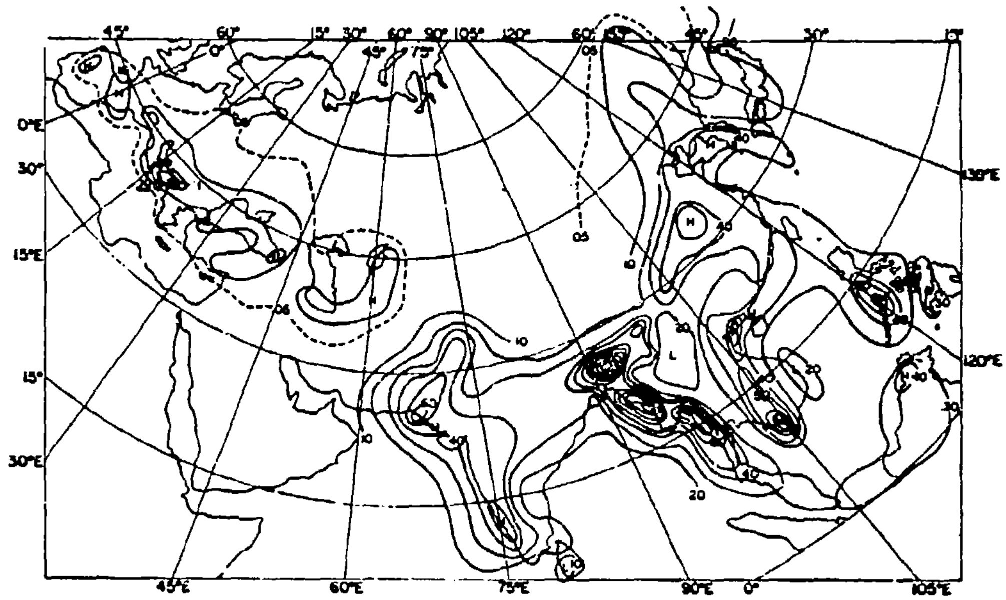

Figure 14. Rainfall Rate (mm/min) Equalled or Exceeded 0.5 Percent of the Time During July

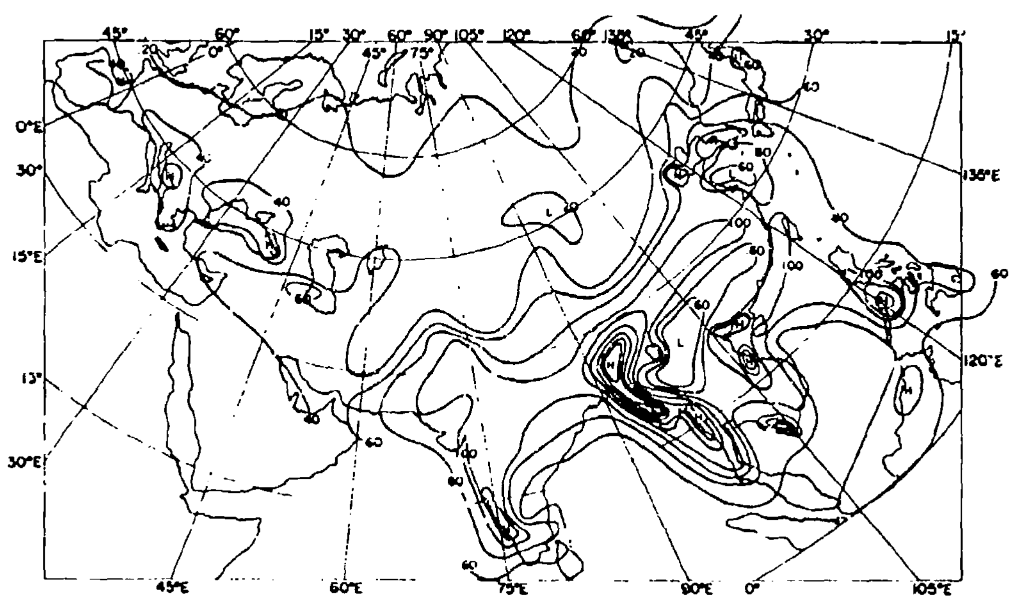

Figure 15. Rainfall Rate (mm/min) Equalled or Exceeded 0.1 Percent of the Time During July

4.1.2.2 Raindrop Sizes (Tattelman and Sissenwine[36])

Sizes of raindrops associated with the extremes of precipitation rate given in Sections 4.1.1 and 4.1.2.1 were determined by Tattelman and Sissenwine.[36] This study showed that the size distribution of raindrops can be estimated using an exponential expression of the form

$$N_D = N_o e^{-\Lambda D}$$

where N_D is the number of drops of unit size range per unit volume, D is the drop diameter, N_o is a fictitious value of N_D, the intercept with the ordinate when D is zero (empirical studies indicate a cutoff in raindrop size between 0 and 0.5 mm), and Λ is a variable which is dependent upon the intensity of the precipitation. The relationship of Λ with rain intensity is fixed by expression

$$\Lambda = aR^b$$

where R is the intensity and a and b are constants. These values vary with the investigator. The size of the median volume raindrops (that is, the diameter that divides drops of larger and smaller diameter into groups of equal total volume), D_o, can be expressed in millimeters by

$$D_o = \frac{3.67}{\Lambda}$$

where $\Lambda(\mathrm{mm}^{-1})$ is dependent on the precipitation intensity, R (mm/hr).

Several authors have derived values for N_o from empirical data for various locations and precipitation characteristics. Since concern herein was with high intensity rainfalls, Tattelman and Sissenwine used values derived from thunderstorm data developed by Jones,[37] since they are most suitable for the rainfall rates required in MIL-STD-210B.

The resulting equation for the distribution of drop sizes is

$$N_D = 389R^{1.02} \exp\left(\frac{-3.67D}{D_o}\right)$$

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36. Tattelman, P.I., and Sissenwine, N. (1973) Extremes of Hydrometeors at Altitude for MIL-STD-210B: Supplement-Drop Size Distributions, AFCRL-TR-73-0008, AFSG 253.

37. Jones, D.M.A. (1956) Raindrop Size Distribution and Radar Reflectivity, Illinois State Water Survey, Research Report No. 6.

where

$$D_o = 1.43R^{0.05} .$$

The above equation can also be integrated to express the total precipitation water content in the form of the equation

$$M = 0.052R^{0.97}$$

where M is the water content (g/m^3) and R the intensity (mm/hr).

To obtain the drop-size distributions for 1 mm intervals, the midvalue for each millimeter class interval of the range of drop diameters was used for D (for example, 1 mm was used for D to compute the number of drops in the 0.50 to 1.49 mm class interval, etc.).

The equation for drop-size distribution indicates that as the drop size D approaches zero, the number of drops continues to increase toward $389R^{1.02}$. This is unrealistic, since it leads to the largest number of drops at zero diameter. This is a result of fitting the distribution of raindrop sizes with a simple equation which neglects physical limitations that govern both large and small sizes attainable in nature. Observations show that there are no drops of less than roughly 0.5 mm diameter during intense rains. The relatively slower terminal velocity of the smallest drops leads to collision and coalescence with faster falling larger drops, producing a sharp diminution of drops at some diameter not much lower than 0.5 mm. For this reason, the smallest size class used for the distributions provided in Table 18 is 0.5 to 1.4 mm. The largest interval is that for 5.5 to 6.4 mm as drops this large and larger are unstable and break up into smaller drops.

Table 18. Number of Drops per m^3 With Given Diameters Associated With the Highest Recorded, 0.1, and 0.5 Percent Precipitation Rate Extremes

Percent Extreme	Rainfall Intensity (mm/min)	Median Diameter (mm)	Diameter (mm) 0.5 to 1.4	1.5 to 2.4	2.5 to 3.4	3.5 to 4.4	4.5 to 5.4	5.5 to 6.4
High. Rec.	31	2.2	158,624	29,915	5642	1064	201	38
0.1	3.13	1.9	11,755	1,704	247	36	5	1
0.5	0.80	1.8	2,626	342	45	6	1	< 1

4.1.2.3 Associated Temperatures and Windspeeds

Nominal temperatures and windspeed associated with the intense precipitation rates given in Sections 4.1.1 and 4.1.2.1 can be found in Byers[38] (p. 464). These are temperatures of 75°F to 80°F and winds of 5 to 8 mps at a height of 10 ft.

4.1.3 WITHSTANDING

4.1.3.1 10 Percent Extreme (Lenhard and Sissenwine[39])

Intense rainfall can affect equipment by hampering or preventing operation of the equipment while the rain is falling. Accumulation of unusual amounts can cause irreversible damage, preventing further operation of equipment after the rain has ceased. The lower limit of the latter of these, termed "withstanding" extremes for design, are of concern in this section.

To withstand rainfall, equipment must be able to survive periods of intense rainfall during expected durations of exposure (EDE) in the field. The length of the periods of intense rainfall that could be critical and the EDE will vary with the equipment. Hence, rainfall intensity data must be provided for various durations of precipitation and EDE's. MIL-STD-210B specifies durations of 1, 12 and 24 hr and EDE's of 2, 5, 10 or 25 years, as considered appropriate for each item of equipment. For these periods, a calculated risk of failure of 10 percent in the most severe geographical area for each climatic element is acceptable for "withstanding."

To determine values of rainfall for various durations, that is, 1, 12, and 24 hr and for various EDE's, the probability theory of Gumbel (see Section I.2.4) is used. Required are tabulations of annual extremes for these durations for many years. Such tabulations of extreme annual precipitation are rare. Although there are many stations throughout the world where precipitation is measured, there are relatively few where amounts are tabulated and published for time periods of less than 24 hr. In tropical regions, where the most intense precipitation is to be expected and is therefore of greatest military interest, published data on annual extremes of rainfall is even less available than for the highly industrialized mid-latitudes. In order to provide climatological information on a worldwide basis, it is necessary to establish a relationship between the data available on extreme rainfall durations for midlatitudes and the usual meteorological observations for which a worldwide climatology is available. Lenhard and Sissenwine[39] used data for 200 stations in the contiguous United States plus stations in Alaska, Hawaii, Hong Kong,

38. Byers, H.R. (1959) General Meteorology, McGraw-Hill Book Co., New York.

39. Lenhard, R.W., and Sissenwine, N. (1973) Extremes of 1, 12, and 24-Hour Rain for MIL-STD-210B, in press (June 1973), AFCRL Air Force Survey in Geophysics.

India, Japan, Okinawa, The Philippines and Puerto Rico to establish such a relationship. Rainfall amounts were extracted for all of the stations for a range of durations of 5 min to 24 hr and EDE's of 2 to 25 years.

The objective of the analysis was to relate extremes of 1, 12, and 24 hr rainfalls to climatological data that is widely available. The simplest hypothesis is that the greatest extremes will occur where the greatest total precipitation occurs and, indeed, there is a correlation between annual precipitation total and the intensity of extreme rainfall that is statistically significant. The relationship is of limited practical value, however, as the correlation is not high and the standard error of estimate of the regression equation is fairly large. A more sophisticated hypothesis is one that would take account of the distribution of the average daily intensity of rainfall. This average precipitation on a rainy day is obtained by dividing the annual precipitation by the number of days on which precipitation occurred, and the parameter has been designated as the precipitation index (I) and is the primary independent variable in the relationships that have been developed. It is quite highly correlated with extreme intensities and the relationship has a standard error that, while larger than desirable, is small enough that estimated intensities have practical value.

Among other predictors tried, only temperature proved worthy of further investigation. The temperature parameter that was found by trial to be most useful was an average measure of the annual temperature range: the difference in mean monthly temperature in Fahrenheit degrees between the warmest and coldest months. This parameter (dT) was taken as the secondary independent variable.

Regression equations were established for each EDE and duration based on data from all stations. A few of these equations were checked against several of the stations with most intense precipitation. There seemed to be some slight tendency to underestimate these extreme values, hence it was decided to select a smaller sample of stations with high rates of precipitation. In the United States these were located near the coast, from South Carolina southward on the Atlantic coast and all along the Gulf coast from Brownsville, Texas to Key West, Florida. All of the stations outside of the United States were included in this smaller sample which consisted of a total of 27 stations.

Regression equations were established based on this sample. The correlations were lower than for the regressions based on all stations, but so was the standard error of estimate. For this small sample, multiple regression was of no value; the contribution to explained variance of the variable dT was not statistically significant nor was the standard error of estimate improved appreciably. Regressions utilizing all stations were improved by the addition of dT as an independent variable in all but the 12 and 24 hr durations. The standard

error of rates estimated from these regressions was, however, larger than for estimates made from regressions on I only, derived from the sample of 27 stations. Since these 27 stations have the most intense precipitation and provide the greater precision of estimate, the model to be developed was based on them.

The estimating equation used is

$$R = A + BI$$

where R is the rain rate in inches per hour and I is the precipitation index in inches per day of rainfall ≥ 0.01 in. The equation can be rewritten with subscripts to denote the particular duration (D) and EDE period (P) under consideration:

$$R_{DP} = A_{DP} + B_{DP} I \; .$$

The required regression equations were determined by least squares and the coefficients (A and B) appeared to increase linearly with the logarithm of P (related to the EDE period). This relationship is expressed by

$$C_{i_D} = a_{i_D} + b_{i_D} \ln P$$

where C_i is the coefficient, either A or B (for example, $A_{12h} = a_{A12} + b_{A12} \ln P$).

This model was fitted by least squares to the 16 sets of values (2 coefficients times 8 durations) with all fits being highly significant statistically. The lowest correlation obtained was 0.967 which provided an F ratio that was significant at the 3 percent level. There also appeared to be a quadratic relationship between the value of a coefficient and D, the duration. This relationship is expressed by

$$\ln K_j = \alpha_j + \beta_j \ln D + \gamma_j \ln^2 D$$

where K_j is the coefficient a_{i_D} or b_{i_D} in the equation for C_{i_D} above (for example, $\ln a_{A_D} = \alpha_A + \beta_A \ln D + \gamma_A \ln^2 D$).

This model was fitted to the four sets of coefficients yielding the following four equations, all with correlations greater than 0.99:

$$\ln A_a = 1.33123 + 0.22135 \ln D - 0.13889 \ln^2 D$$

$$\ln A_b = -0.46243 + 0.33652 \ln D - 0.09462 \ln^2 D$$

$$\ln B_a = 0.58770 + 0.15912 \ln D - 0.05524 \ln^2 D$$

$$\ln B_b = 0.81299 - 0.62919 \ln D + 0.02514 \ln^2 D$$

The equations for R and CI_D can be combined into a general equation

$$R_c = (A_a + A_b \ln P) + (B_a + B_b \ln P)I$$

and the values of the coefficients A_a, A_b, B_a and B_b determined from the four equations above. Here R_c is used to designate the computed or estimated value of precipitation as distinguished from R, the observed value that was the input to the anaylsis.

To obtain values of R for MIL-STD-210B using the above equations, a value must be assigned to the precipitation index I. This should be representative of the most severe geographical area. The areas with most intense rainfall are found in Africa on the Gold Coast, in South America in Columbia and in the Philippines, Indonesia, Southeast Asia and India. The annual precipitation index was calculated for a number of stations in the Asian region which has the largest area of intense rainfall. A few stations have an index greater than 1 in. per rain day of 0.01 in. or more, but these are relatively rare and isolated. Most of Southeast Asia, India, Indonesia and the Philippines have an index greater than 0.5 in. per day. A number of stations in Burma and Southeast Asia yielded index values above 0.75 in. per day and formed coherent regional patterns. This index value appeared to be representative of areas of greatest rainfall intensity without being of such unusual occurrence as to produce an unrealistically stringent design criterion that would cause excessive over-design of equipment. Hence I = 0.75 was selected for input into Eqs. (4) and (5) for calculating values of intense rainfall for MIL-STD-210B.

For the purposes of MIL-STD-210B, the durations of interest are 1, 12 and 24 hr and the EDE periods, 2, 5, 10 and 25 years. The coefficients for these combinations are given in Table 19 and the MIL-STD-210B values in Table 20.

4.1.3.2 Associated Temperature and Windspeed

The rain rates for 1, 12, and 24 hr given in Section 4.1.3.1 often occur with the passage of a tropical storm. Nominal temperatures and windspeeds associated with tropical storms can be found in Byers[38] (pp 384-387). These are a temperature of near 75°F and windspeeds of approximately 33 mps for the 1 hr intensity, 26 mps for the 12 hr intensity, and 21 mps for the 24 hr intensity (for anemometer heights of 10 ft).

Table 19. Coefficients for Use in Calculating Withstanding Rain Rates Using Regression Equations

Coeff.	Duration (hr)		
	1	12	24
A(a)	0.9132	0.0398	0.0122
A(b)	0.5113	0.0959	0.0488
B(a)	1.3678	0.4693	0.3083
B(b)	0.2514	0.0966	0.0778
2 yr A	2.4450	0.3272	0.1585
B	2.1209	0.7588	0.5413
5 yr A	2.9135	0.4151	0.2033
B	2.3512	0.8473	0.6125
10 yr A	3.2679	0.4815	0.2371
B	2.5255	0.9143	0.6664
25 yr A	3.7364	0.5694	0.2819
B	2.7559	1.0028	0.7377

Table 20. Withstanding Precipitation Rate Extremes (in/hr) for MIL-STD-210B

Duration (hr)	Estimated Duration of Exposure (yr)			
	2	5	10	25
1	4.04	4.68	5.16	5.80
12	0.90	1.05	1.17	1.32
24	0.56	0.66	0.74	0.84

4.2 Snow

Effects of snow on military equipment are of different kinds, and the design criteria depend on the nature of the equipment.

(1) Snow affects military equipment in three basic ways:

(a) By impeding movement through accumulation on the ground. This aspect, while of great importance, is not within the scope of this report.

(b) By impeding operation of equipment through accumulation on moving parts or electrical components, such as sifting into radios, clogging air vents, and packing into recoil tracks. This aspect is associated with instantaneous/short-period snowfall rates and is most important when the snow is windblown; it is discussed in Section 4.2.1.

(c) By imposing a structural load on buildings, shelters, and vehicles. This snowload aspect is examined in Section 4.2.2.

4.2.1 BLOWING SNOW

Mellor[40] has prepared an excellent treatise and review on blowing snow. He discusses snow transport mechanisms, the size and fall velocity of blown snow particles, concentration and mass flux of blown snow particles, concentration and mass flux of blown snow, measuring blowing snow, mass drifting and its control, visibility during blowing snow, and effects of blowing snow. From this review (Mellor[40]), it is possible to determine extremes of blowing snow for MIL-STD-210B purposes.

Extremes of blowing snow given in the following sections are in terms of horizontal mass flux of snow particles; that is, the mass of snow moving horizontally across a unit area per unit time. Mass flux decreases significantly with increasing height; highest fluxes are found below about 0.05 m (2 in.) but significant fluxes occur above this level up to 10 m (33 ft). Therefore, extremes of blowing snow are provided for heights intervals up to 10 m (33 ft). Design values should be based on the height of the equipment.

4.2.1.1 Highest Recorded

Highest recorded blowing snow extremes, horizontal mass fluxes ($gm^{-2}sec^{-1}$), are available (Figure A4 by Mellor) as a function of windspeed for heights of 4, 2, 1, 0.5, 0.25, 0.12, 0.06, and 0.03 m. These fluxes were plotted on logarithm paper to obtain values at standard heights because extremes of blowing snow decrease exponentially with height. The highest recorded values are given in Table 21. These values are also most probably the maximum values physically possible because they are essentially saturation values. The windspeeds associated with the highest recorded values were between 25 and 32 mps, with an

40. Mellor, M. (1965) Blowing Snow, Cold Regions Science and Engineering. Part III, Section A3c, Cold Regions Research and Engineering Laboratory, Hanover, New Hampshire.

Table 21. Highest Recorded Mass Fluxes of Blowing Snow as a Function of Distance Above the Ground

Height		Mass Flux	
(m)	(ft)	($gm/m^2/sec$)	($lb/ft^2/sec$)
10	33	310	63×10^{-3}
7.5	25	320	66×10^{-3}
5.0	16	330	68×10^{-3}
2.5	8.2	380	78×10^{-3}
1.0	3.3	560	110×10^{-3}
0.75	2.5	630	130×10^{-3}
0.50	1.6	800	160×10^{-3}
0.25	0.82	1600	330×10^{-3}
0.10	0.33	3000	610×10^{-3}
0.05	0.16	6200	1300×10^{-3}

average of 27.1 mps. These are for a height of 10 m. The average speed was adjusted to the MIL-STD-210B standard height of 10 ft, using the factor of 1.61 provided by Sissenwine et al,[26] resulting in an associated speed of 23.3 mps at 10 ft.

4.2.1.2 Operations

One percent blowing snow extremes can be determined from information provided in Mellor's[40] Figure 13. It provides mass fluxes of blowing snow versus height for six windspeeds between 11.7 and 22.1 mps at a height of 10 m. One also needs the windspeed that occurs 1 percent of the time when and where snow is continuous on the ground, since wind is the basic cause of blowing snow. The 1 percent windspeed, obtained from USAF GRD,[10] found over central Canada during January is equal to 30 mph at a height of 10 ft. This windspeed was adjusted to 10 m for use in Mellor's[40] Figure 13, with a factor of 1.161 (Sissenwine et al[26]). The adjusted wind is 34.8 mph (15.6 mps). For a speed of 15.6 mps, the blowing snow extremes obtained are provided in Table 22.

4.2.1.3 Particle Size Distribution

When blown by strong winds, snow crystals are broken and abraded into roughly equidimensional grains with rounded or subangular corners. Particles occur in greatest numbers in the size range 20 to 400 μm (Dept. of Army[25]) where size is the effective diameter defined as (length $\times$ breadth)$^{1/2}$ in the plane of measurement. Particle size decreases rapidly with height from the surface to 0.05 m (2 in.) and slowly above this level (Mellor[40]). A typical distribution of

Table 22. One-Percent Extremes of Blowing Snow as a Function of Distance Above the Ground

Height		Mass Flux	
(m)	(ft)	$(gm/m^2/sec)$	$(lb/ft^2/sec)$
10	33	2.2	0.45×10^{-3}
7.5	25	3.3	0.68×10^{-3}
5.0	16	4.0	0.82×10^{-3}
2.5	8.2	6.9	1.4×10^{-3}
1.0	3.3	16	3.3×10^{-3}
0.75	2.5	22	4.5×10^{-3}
0.50	1.6	32	6.6×10^{-3}
0.25	0.82	66	14×10^{-3}
0.10	0.33	200	41×10^{-3}
0.05	0.16	530	109×10^{-3}

blowing snow particle sizes applicable to Table 22, given by Mellor in his Figure 7 at a height of 0.2 m, is provided in Table 23. Temperatures during periods of such extremes of blowing snow are typically -10°C to -20°C.

Table 23. Particle Sizes During Episodes of Blowing Snow

	Effective Diameters (μm)												
	23 to 34	35 to 46	47 to 58	59 to 70	71 to 82	83 to 94	95 to 106	107 to 118	119 to 130	131 to 142	143 to 154	155 to 166	167 to 178
Distribution (Percent)	0.60	1.3	5.0	15	22	21	16	9.7	4.7	2.5	1.0	0.70	0.50

4.2.1.4 Withstanding

Blowing snow is considered only an operational problem. Therefore, withstanding extremes are not applicable.

4.2.2 SNOWLOAD

The design of buildings and many types of outdoor structures requires estimates of the stresses caused by heavier snowfalls and their consequent snowloads. Collapse of a structure through inability to withstand the load imposed by accumulated snow may cause damage to equipment and injury to personnel, but

choice of design criteria for shelters to eliminate this contingency is very difficult. Decisions must be made as to the degree of risk to be assumed, since any increase in the bearing strength of a shelter increases its weight and cost, thereby decreasing its portability and utility.

Greatest falls of snow (potential snowload) are encountered when temperatures are just below freezing. Areas of maximum annual total snowload potential (deepest snow) generally occur in the southern parts of areas having cold winters and particularly in parts of these areas dominated by a maritime climate. Extremely heavy individual snowstorms generally occur even farther south in warmer air where more moisture is available. Such snowfalls are usually followed by melting, and even in years when such heavy snows do fall, amounts on the ground at any one time are not as great and do not accumulate to the depths that may be observed at places farther north.

Snowload depends on snow density as well as depth of deposit. The density of falling and new fallen snow can vary widely from the usually assumed value of 0.1; densities in the range of 0.07 to 0.15 are not uncommon. If snow is allowed to accumulate, it ages and becomes more compact and increases in density. This process may be aided by rain and/or successive periods of thaw followed by freezing. Old snow generally has a density of 0.2 to 0.4. For determining snowload from snow depth measurements, one should use a density closer to 0.1 than to 0.4 because maximum snowloads usually occur when appreciable new snow (light density) covers an existing higher density snow. Sissenwine and Court[2] recommend using a density of 0.1 for snowload design purposes whereas Boyd[41] uses a value of 0.192.

Because snowloads on structures are not routinely measured, estimates of structure snowloads must be obtained from surface measured snow accumulations. Such estimates may be questionable and considerably in error because snow accumulation on structures will usually be much less than on the ground because of structure slope, heating, and usually windier exposure.

Shelters and similar military combat equipment cannot be built to withstand the heaviest known snowloads without becoming completely immobile. Therefore, snowload design criteria are proposed for three types of transportable equipment:*

(1) Semipermanently installed equipment*, demountable and mobile. It may be located any place in the temperate or Arctic regions. Snow usually is not

*Snowload criteria for permanently installed equipment, which is built and designed for a specific location (for example, a warehouse in an extremely snowy mountain area), must be determined by the architect based upon the maximum snowload ever observed or expected in that location.

41. Boyd, D.W. (1961) Maximum Snow Depths and Snowloads on Roofs in Canada, Research Paper No. 142, Division of Building Research, National Research Council, Canada, Ottawa.

removed between snowfalls. The snowload (withstanding) criterion should be based upon snowloads to be expected during one winter season taking a calculated risk of 10 percent.

(2) Temporary equipment, usually large shelters such as a portable hangar from which snow can be cleared between storms. This class of equipment will not sag appreciably due to the snowloading, but will collapse when its limits are reached. The snowload (withstanding) criterion should be based upon the maximum snowload expected in any one storm during a winter season taking a calculated risk of 10 percent.

(3) Portable equipment, usually small, such as tentage, which may be moved daily. This equipment generally will shed snow, but in instances where it does not, distortion will be noticeable and daily clearing mandatory. The design (withstanding) criterion for such equipment shall be determined on the expected maximum 24 hr snowfall during a winter season taking a calculated risk of 10 percent.

4.2.2.1 Highest Recorded

As indicated previously snowloads on structures are not measured, but inferred from surface snowfall/snow depth measurements. Therefore, only these data can be presented as an indication of highest observed snowloads. Corresponding to the three categories of structures, three types of record extremes are presented: (1) greatest one season snowfalls and accumulations, (2) greatest one storm snowfalls, and (3) greatest 24 hr snowfalls. For the most part, only data for the contiguous United States is presented; such data should, however, be not too different from worldwide extremes as certain sections of the United States are among the snowiest places in the world.

4.2.2.1.1 SEASONAL

The greatest seasonal snowfall recorded in the United States was 1027 in. at Paradise Ranger Station (elevation, 5,427 ft) on Mt. Rainier in Washington during 1970-1971 (Ludlum[42]). This exceeds the previously quoted (Sissenwine and Court[2]) world extreme seasonal snowfall of 884 in. at Tamarack, California in 1906-1907. These records are the sum of individual snowfalls and not the depth on the ground at any one time. The United States greatest depth of snow on the ground was 451 in. at Tamarack on 11 March 1911 (Riordan[8]). For an assumed snow density of 0.1, this corresponds to a ground snowload of 235 lb/ft^2; if the density were 0.2, the ground snowload would be 470 lb/ft^2. However, both of these stations are in mountainous locations and are probably not representative of snow accumulations in areas where military equipment would generally operate or be stored.

42. Ludlum, D. (Ed.) (1971b) New U.S. seasonal snowfall record, Weatherwise 24, 4:163.

Boyd[41] in a study of nonmountainous Canadian snowfall statistics to estimate ground snowloads, indicates that maximum ground snowload of 120 lb/ft^2 can be expected to occur once in 30 years in non-mountainous sections of Canada. A U.S. Weather Bureau[43] study, also using snowfall statistics, estimates the maximum (nonmountainous) United States ground snowload to be 60 lb/ft^2 and the 1 year in 10 maximum to be 40 lb/ft^2.

4.2.2.1.2 SINGLE STORM

The greatest single storm snowfall record is 189 in. at the Mt. Shasta, California Ski Bowl, 13-19 February 1959 (Riordan[8]). This results in a ground snowload estimate of 98.5 lb/ft^2, assuming a snow density of 0.1 for newly fallen snow. Again such a location is not representative of normal military operation areas, so one should look at records from nonmountainous locations. The Environmental Science Services Administration[44] has tabulated outstanding snowfalls going back to the 1700's. They list a New England 19-24 February 1717 snowfall of 60 to 72 in., a New England 11-14 March 1888 snowfall of 50 in., a Watertown, New York 18-22 January 1922 fall of 69 in., and a Vermont 2-5 March 1947 snowfall of 50 in. One could doubt the authenticity of the 1717 New England snowfall, but the Watertown record of 69 in. should be taken as the maximum nonmountainous one storm snowfall. Assuming again 0.1 snow density, this translates into a ground snowload of 39 lb/ft^2. The heavy snows common to Watertown are due in part to the proximity of the Great Lakes. Away from such a moisture source, a more representative single-storm snowfall record is about 50 in., or a ground snowload estimate of 26 lb/ft^2 for an assumed snow density of 0.1.

4.2.2.1.3 24-HR SNOWFALL

Data is not available for the world record, but the North American greatest 24 hr snowfall is 76 in. at Silver Lake, Colorado 14-15 April 1921 (Riordan[8]).

Silver Lake is located at approximately 40°N, 105°40'W, at 10,220 ft elevation in the Colorado Rockies. The snowfall there in April 1921 established several records: 76 in. in 24 hr, prorated from a measured fall of 87 in. in 27-1/2 hr, 95 in. in 32-1/2 hr, 98 in. in 72 hr, and 100 in. in 85 hr. The measurement was examined thoroughly before being accepted by the U.S. Weather Bureau. They indicated that there was no evidence to indicate that the measurement was any less reliable than that of other heavy snowfalls, and it appears that a snowfall

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43. U.S. Weather Bureau (1951) Determination of Snowloads for Building Construction, Division of Climatological and Hydrological Services, Washington, D.C.

44. Environmental Science Services Administration (1966) Some Outstanding Snowstorms, LS 6211, Environmental Data Service, Washington, D.C.

of this magnitude is meteorologically possible. The maximum amount of snow that can fall in 24 hr has been estimated as approximately 72 in. for snow with a density of 0.10 under normal packing conditions, and correspondingly greater for lesser density. The density of the snow at Silver Lake was 0.06. During the storm, thunder occurred in various parts of the region, indicating widespread convective activity, and the combined convective and orographic influences produced excessive amounts of snow at several places. In addition to the record at Silver Lake, a fall of 62 in. in 22 hr was reported at Fry's Ranch, Colorado; both of these exceeded the previous United States record of 60 in. in 24 hr at Giant Forest, California in January 1933. The Silver Lake snowfall occurred in a mountainous location and would have resulted in an estimated ground snowload of 39.5 lb/ft^2 (snow density, 0.1).

Nonmountainous 24 hr record snowfalls listed in Environmental Science Services Administration[44] are: Middletown, Connecticut, March 1888, 28 in.; and Watertown, New York, November 1900, 45 in. The Watertown record snowfall gives an estimated ground snowload of 23.4 lb/ft^2, and the Middletown record gives 14.6 lb/ft^2.

4.2.2.2 Operations

Snowload is not an operational problem but a withstanding one.

4.2.2.3 Withstanding

4.2.2.3.1 SEMIPERMANENT EQUIPMENT

This is, by definition, equipment on which snow is allowed to accumulate for one season. For design purposes, the structural snowload that will be equalled (or exceeded) with only a 10 percent probability (say 1 season out of 10 seasons) in the snowiest non-mountainous locations is desired. Only estimates of ground snowloads from a location which is probably representative of the non-mountainous snowiest location are available. A Canadian study (Boyd[41]) shows a ground snowload maxima of 120 lb/ft^2; this maximum is to be expected once in 30 years or with a 3 1/3 percent probability in any one year. Also available are ground snowload estimates for the United States published by the Weather Bureau;[43] these are ground snowloads that can be expected once in 10 years or with a 10 percent probability in any one year. (Both studies assumed a snow density of approximately 0.2 to arrive at snowload estimates.) Based on the snowiest areas where the estimates from the two studies overlap (northwestern Maine), it appears that 2/3 of Boyds' 3 1/3 percent probability estimates are equivalent to a 10 percent probability for a year. This gives an estimated maximum ground snowload of 80 lb/ft^2 (2/3 of 120 lb/ft^2) which can be equalled or exceeded with a 10 percent probability. To convert the ground snowloads to structure snowloads, guidelines

are given by the National Research Council of Canada (Lutes[45]). This agency conducted a survey of snowloads on roofs (1957-1967) and in particular compared roof snowloads with ground snowloads. On the basis of these observations and until more information was available, they recommended that the design snowload for exposed flat or low-slope roofs be 60 percent of the maximum ground snowload. This results in a structural snowload design criteria of 48 lb/ft^2 for exposed and flat or low-sloped semipermanent equipment. Lower snowload design criteria are recommended for more steep sloping structures and also structures which are subject to substantial heating.

4.2.2.3.2 TEMPORARY EQUIPMENT

Design for temporary equipment is based upon the maximum weight of snow that can be expected to fall in one storm. Presented in Section 4.2.2.1.2 were storm snowfalls of 69 in. at Watertown, New York yielding an estimated snowload of 39 lb/ft^2, and of 50 in. at other locations for a snowload of 26 lb/ft^2. These are extremes and not the values that can be expected with a 10 percent probability. Sissenwine and Court[2] in a study of 129 regular Weather Bureau stations (large cities), noted that three stations (2 percent) had observed snowfalls from a single storm of more than 40 in., 13 (10 percent) of more than 30 in., and 43 (33 percent) of more than 20 in. Based on these figures, it seems reasonable and conservative to recommend a single storm snowfall of 40 in. as one that has a 10 percent probability. For a newly-fallen snow of 0.1 density, this gives an estimated snowload of approximately 20 lb/ft^2. This is the same value for temporary equipment as in MIL-STD-210A.

4.2.2.3.3 PORTABLE EQUIPMENT

Design criteria for portable equipment is based on maximum snowfalls for 24 hr periods. Sissenwine and Court[2] show that of 176 U.S. stations, 31 had snowfalls exceeding 20 in. in 24 hr and 4 recorded 30 in. in a day. At each of 14 places at which maximum 24 hr snowfalls exceeded 24 in., statistical analyses of the heaviest 24 hr snowfalls in each of 50 years shows that 24 hr falls exceeding 20 in. are likely to occur, on the average, only once in about 30 years. This value of 20 in. of snowfall in 24 hr. is therefore the amount which has a 10 percent probability of occurring in any 3 year period. Information to calculate the 24 hr snowfall that has a 10 percent probability of occurring in any one full year is not available, but would be slightly less than 20 in.

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45. Lutes, D. A. (1972) Recommended Design Criteria for Roof Snowloads as Outlined in the National Building Code of Canada (Letter Concerning), Personal Communication (I-18, 756, M43-13-27, M43-3-182), 14 March 1972, Building Structures Section, National Research Council of Canada, Ottawa.

Twenty inches of snow for a 24 hr period yields a snowload of about 10 lb/ft^2 for an assumed density of 0.1. This value is recommended as the design criteria for portable equipment; it is also the MIL-STD-210A value.

4.3 Ice Accretion (Grantham and Tattelman[46])

Ice on structures and components can cause extensive damage to military equipment located in high latitude temperate and subarctic cyclonic storm tracks. High isolated mountain peaks anyplace in the world are also subject to icing when crossed by supercooled liquid clouds resulting from any cloud forming phenomena. Concurrent, or more probably subsequent strong winds, may be the critical factor in damaging equipment already loaded with ice.

Glaze ice occurs when rain (sometimes drizzle) freezes on objects; it is clear and nearly as dense as pure ice. Rime ice occurs when supercooled clouds or fog droplets (also sometimes drizzle) freeze upon impact with surfaces colder than 0°C. It is white colored and much less dense than glaze.

Design criteria included in MIL-STD-210B are based upon values having specific probabilities of occurrence. These can only be readily developed when routine observations of the element are available over a period of years. Unfortunately, quantitative records of glaze and rime are not available because icing has not been routinely observed at operational weather stations. (The Design Climatology Branch, AFCRL has just developed prototype instrumentation and is planning such a program of observations.)

Glaze and rime are usually recorded only when they have caused human distress or a sizeable amount of damage. Even then, measurements are not standardized and observations are difficult to compare.

In order to determine reasonable values of ice and wind loading, it is necessary to study case histories of major ice storms, when structures have failed due to the strain of combined ice and wind loading. Such a special study was recently completed to provide design criteria for 400 ft tall antenna towers that are to be installed any place in the world and withstand icing extremes for at least 5 years (Grantham and Tattelman[46]). An estimated 10 percent risk of failure was acceptable. The criteria recommended in that special study are recommended for MIL-STD-210B until data are available to calculate actual 10 percent withstanding extremes for various EDE's.

4.3.1 HIGHEST RECORDED.

Not available.

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46. Grantham, D.D., and Tattelman, P.I. (1972) Wind and Icing Design Criteria for LORAN D Towers, RCS-2-9, AFCRL (LKI) 14 March 1972.

4.3.2 OPERATIONS

Frequency of ice accretion occurrence is normally so low that equipment inoperability during the percent of time of icing occurrence would be an acceptable risk. When icing does occur, however, ice accumulated on a structure is likely to remain for several days; therefore, equipment should be designed to operate with icing up to values provided for withstanding.

4.3.3 WITHSTANDING

These values are estimated to have a 10 percent probability of occurrence during several years of exposure in icing-prone locations. More severe conditions will be found on cloud-immersed mountain peaks during periods of continuous passage of supercooled water clouds (specific design criteria will be required for equipment designed especially for such installations). Strong winds are frequently associated with icing, occurring during its formation or after it has formed but before melting. Forces of such winds must be added to forces due to ice accretion, as part of the stress in design for ice accretion.

Values of ice provided below are thicknesses extending horizontally into the wind. They apply to structures extending up to heights of 400 ft. Associated wind loading can be considered as gusts of 100 knots at about 30 ft. increasing to 123 knots at 400 ft. Independent design considerations shall be for the value of each of the three types of icing below:

(1) 3 in. (76 mm) glaze, specific gravity 0.9.

(2) 6 in. (152 mm) glaze and rime mixed, specific gravity 0.5.

(3) 6 in. (152 mm) rime near the surface increasing linearly to 20 in. (508 mm) at 400 ft, specific gravity 0.2.

4.4 Hail Size (Gringorten[47])

Hailstones are potentially damaging to military equipment depending on size, hardness, number density and impact velocity. To take into account all factors is difficult or impossible.

For this study, the criterion of hailstorm intensity was arbitrarily restricted by Gringorten to maximum hailstone size in each storm. It is tacitly, or even explicitly, assumed by several authors to be sufficient. Damage to crops is believed by some to occur with hailstones of the size of golf balls, approximately 1.6 in. in diamater. Another author writes that wheat, corn and soybean crop damage occurs even with 1/4 in. stones due to a high number density of hailstones.

47. Gringorten, I.I. (1972) Hailstone Extremes for Design, AFCRL-72-0081.

With respect to equipment or installations on the ground, it is more reasonable to expect the hailstone size to be a primary factor. One report indicates that to damage metal surfaces of a parked DC6 airplane, stones would have to be 3 in. in diameter.

The decision to restrict study of hailstorms to the maximum hailstone diameters was strengthened by studies that relate one of the other important factors, the terminal velocity, to the diameter. At the surface, hailstones of the same size will impact a horizontal surface with equal energy since they would be falling with the same speed.

Estimates of the frequency distribution of maximum hailstone diameter per hailstorm for different ranges of hailstone sizes have been published as early as 1899 and in the most recent literature. Using these estimates, Gringorten developed a composite graph, Figure 16, giving an estimate of P(h|H), the cumulative probability of the maximum hailstone diameter h in a hailstorm given that there is a hailstorm (H).

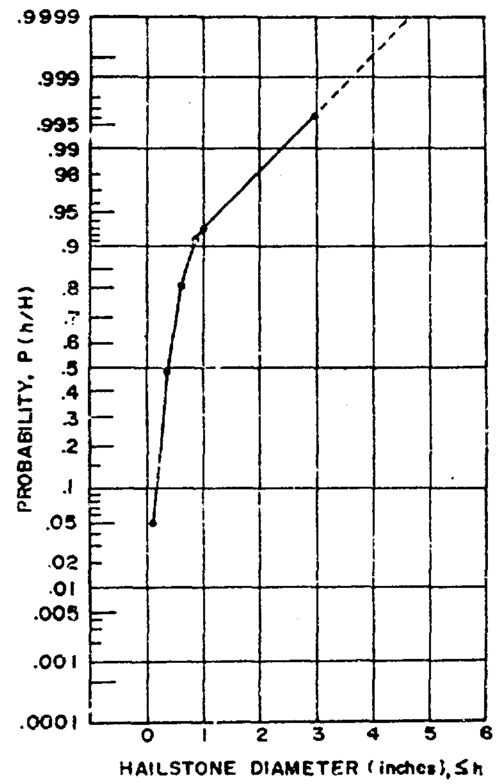

Figure 16. Composite Estimate of (P(h|H), the Cumulative Probability of the Maximum Hailstone Diameter h in a Hailstorm Given That There is a Hailstorm (H)

Following the practice for the MIL-STD-210B studies, it was necessary to decide on the most severe location for hailstorms and the most severe month. The United States has the dubious distinction of being a prime center for hail activity. Western Nebraska or southeastern Wyoming is the center of U.S. hail activity. The greatest average number of hailstorm days in the United States is at Cheyenne, Wyoming, with 9.4 days per season, based on 40 years of record. But such an extreme number is so localized in area that the value 7 per year is probably a more representative estimate. For the most severe month in the most severe location, on the average 2.9 hailstorms occur. A more representative worst area average is assumed to be 2 per month.

Also needed to determine the probability of a hail encounter is the mean

duration of a storm. Gringorten reviewed studies dating back to 1899 and determined that the average point duration for the "most severe area" in the "most severe month" is about 10 min.

Several authors show that the average width of a swath of hailstone incidence is between 1 and 2 1/2 miles; however, this width can be highly variable ranging from a few yards to 75 miles.

The length of the path is considerably greater than the width, but more difficult to define. In a recent study of well-defined hailstreaks, frequency distributions of the maximum widths and lengths of Illinois and S. Dakota hailstreaks were presented, showing widths in Illinois varying from 1/10 mile to 4 miles and lengths from 1 to more than 15 miles. The median width was 1.1 miles in Illinois, but 2.3 miles in S. Dakota. The median length was 5.0 miles in Illinois, 15.3 miles in S. Dakota, thus making the ratio of width to length roughly 1 to 6. All told, as previously mentioned, the S. Dakota hailstreak is 2.7 times greater than in Illinois. The areal extent of the hailstreaks ranged from 1 to nearly 800 square miles.

With regards to the areal frequency of hailstorm days versus the single-point frequency, observations for 10 years at a network of some 50 stations in a 150 square mile area around Denver, gave the average ratio of occurrence of hailstorm days in the area to the occurrence at a single station as 4.4 to 1. This ratio appears to be directly related to area size and to be independent of geography.

Other factors worth mentioning in a discussion of hail for design purposes are density and terminal velocity. The density of hailstones is a variable and documented figures of density are scarce. In a recent paper on estimates of the density of large natural hailstones (8 to 21 gm) in several storms in the United States midwest, density figures ranged from 0.828 to 0.867 gm/cm^3. A rounded value of 0.9 is deemed acceptable as a convervative estimate in calculations of impact energy.

The results of most authors indicate that the terminal velocity (w) of hail can be related directly to the hailstone diameter (d); that is,

$$w = K\sqrt{d} \quad .$$

For w in cm/sec, d in cm, K values at the surface ranging from 1150 to 1990 have been found.

4.4.1 LARGEST RECORDED

For a number of years the largest hailstone on record had been 5.4 in. at Potter, Nebraska, 6 July 1928. Extrapolation of the curve of Figure 16 gives this size a probability of one chance in 27,000 hailstorms (0.0037 percent).

Recently (Ludlam[48]), a photograph was published of a hailstone, irregular in shape, with diameter approximately 5.6 in., that fell in Coffeyville, Kansas, 3 September 1970.

4.4.2 OPERATIONS

As previously discussed for the most severe area in the most severe month, a frequency of 2 hailstorms per month each lasting an average of 10 min can be assumed. Since there are 44,640 min in a month, hailstorms can be expected to occur only 0.0448 percent or about 0.05 percent of the time in the worst location and month.

This risk corresponds to a probability P(H) of 0.000448 for any one minute. Thus the probabilities of exceedance, $P(\geq h)$, of hailstone diameters ($\geq h$) at a single station can now be calculated, using p(H) and $P(h|H)$

$$P(\geq h) = p(H) \times [1 - P(h|H)] .$$

These probabilities and percent extremes are listed in Table 24. Even during the worst month in the worst location, the probability/percent risk of encountering

Table 24. Operational Hail Size (Percent) Extremes—Estimates of the Probability of Encountering Hailstones of Given Diameter at a Single-Point Location

Hail Diameter (in.) (h)	Conditional Probability of Size $\geq$h	Single-Station Probability	Approximate % Extreme
Any size	1.000	0.000448	0.05
$\geq$ 0.25	0.790	0.000354	0.04
$\geq$ 0.5	0.360	0.000161	0.02
$\geq$ 0.75	0.135	0.0000605	0.01
$\geq$ 1.0	0.070	0.0000314	0.003
$\geq$ 2.0	0.019	0.00000851	0.0009
$\geq$ 3.0	0.0038	0.00000170	0.0002
$\geq$ 4.0	0.00055	0.00000025	0.00003

Note:

Values in this table should be used when failure of operating equipment due to hail would endanger life.

48. Ludlam, D. (Ed.) (1971a) The new champ hailstone, Weatherwise 24, 4:51.

a significantly large hailstone is extremely small at a randomly selected instant. Therefore, in design, hail size extremes need not be considered for operating most surface equipment. However, for equipment whose operational failure due to hail would result in the endangerment of life, the largest hail size on record (5.6 in.) should be used as a design criteria if such an extreme is at all possible to accommodate in the design of a particular item. When design for the record size is not feasible, the attendant percent risk for the design that is possible can be obtained from Table 24.

4.4.3 WITHSTANDING

As discussed in Section I.2.4, withstanding extremes are based on annual extremes of a particular element. However, the size of the largest hailstone that fell in any given year over a period of a number of years is not known. Therefore, Gringorten[47] had to resort to another statistical technique to determine hail size withstanding extremes. He basically combined the probability of the occurrence of a certain number of hailstorm days per year with the probability of hail of a certain size in any given hailstorm (Figure 16).

For the probability of a certain number of hailstorm days per year, the Poisson distribution had been found applicable. If the average is h hailstorm days per year, assumed independent of each other, then for the probability of n hailstorm days per year, the Poisson distribution gives

$$p(n) = c^{-h}\left(\frac{hn}{n!}\right).$$

An accepted value for h is 7 per year as discussed in the introduction to Section 4.4.

Figure 16 gives the cumulative probability distribution $P(h|H)$ of maximum hailstone size ($\leq h$) on any one hailstorm day. The cumulative probability distribution of the maximum size in n independent hailstorm days is thus given by $P^n(h|H)$. Therefore, the cumulative probability of hailstones equal to or less than size h for a whole year is given by

$$\sum_{n=0}^{\infty} p(n) \cdot P^n(h|H) \quad .$$

This cumulative probability is closely approximated by assuming an upper limit of n = 20 storms per year.

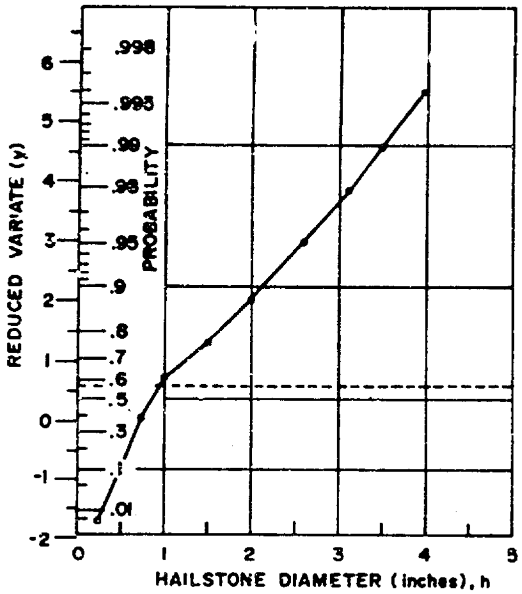

Figure 17. Cumulative Probability of the Annual Largest Hailstone Diameter in the Most Severe Location, Plotted on Extreme Probability Paper

Figure 17 shows the plot of this probability for size h varying from 0.25 to 4.0 in. on extreme probability paper. As discussed and exemplified in Section I.2.4, it is possible with such a plot to determine withstanding extremes for various risks and various equipment EDE's. For the recommended 10 percent risk and for EDE's of 2, 5, 10, and 25 years, hail size extremes and their respective terminal velocities which surface equipment should withstand are:

EDE (yr)	10 Percent Withstanding Extreme (in. in diam)	Terminal Vel.*
2	2.6	42 m/sec
5	3.1	46 m/sec
10	3.5	49 m/sec
25	4.0	52 m/sec

5. PRESSURE

Atmospheric pressure is usually not considered in the design and testing of most military equipment. Ambient pressure may be important for certain types of equipment, however, for instance those which require oxygen in combustion, and those sealed units which might explode or collapse under abnormally low and high pressure, respectively.

* Computed using $w = K\sqrt{d(cm)}$, with K = 1630.

Standard atmospheric pressure at sea level is 1013.2 mb, 29.92 in. of mercury, or 14.7 lb/in.^{2}. However, much higher pressures are found in winter polar air masses, summer subtropical anticyclones, and also at below sea level locations; much lower pressures occur in tropical storms and especially tornadoes, and of course with increasing elevations from sea level.

Pressures shown on surface weather maps are station pressures reduced to sea level. These artificial pressures are obtained by increasing station pressures for stations above sea level and by decreasing station pressure for stations below sea level; the increase or decrease is a function of station elevation and current temperature. Therefore, only pressures taken near the coast, over water, or near sea level represent true sea level pressure extremes.

For the design of military ground equipment, however, it is not so much the sea level extremes that are important but actual pressure extremes where military equipment is likely to be used or stored.

5.1 High Pressure

5.1.1 HIGHEST RECORDED (Loewe[49])

The highest observed (not reduced to sea level) pressures have occurred in the Dead Sea area. A pressure of 1081.8 mb (31.95 in., 15.69 lb/in.^{2}) was observed at Sedom, Israel on 21 February 1961 (Court[50]). Excluding such isolated below sea level locations, the highest actual pressures occur near sea level in Siberia. Loewe[49] in his note on high pressure extremes presents evidence that actual pressures in these locations may reach 1080 mb (31.89 in., 15.65 lb/in.^{2}). Station pressures over 1050 mb are estimated to have occurred in the contiguous United States in the Gulf of Mexico, off the Oregon-California coast, and in southern New England, New Jersey, and adjacent areas.

5.1.2 OPERATIONS

A determination of the 1 percent operational high pressure extreme (the actual not reduced to sea level pressure that is equalled or exceeded during 1 percent or more of the time (hours) in areas having the highest pressures during the time of year when high pressures are most common) has not been made, since it is presumed that designing for a pressure extreme of 1080 mb is neither an economic nor a technological problem.

49. Loewe, F. (1969) More on improbable pressure extreme: 1070 mb, Bull. Am. Meteorol. Soc. 50, 10:804-806.

50. Court, A. (1969) Improbable pressure extreme: 1070 mb., Bull. Am. Meteorol. Soc. 50, 4:248-250.

5.1.3 WITHSTANDING

A determination of the 10 percent withstanding high pressure extreme (that value of pressure that has a 10 percent probability of occurring or being exceeded during various planned lifetimes (years) or equipment in an extreme area and season) has not been made for reasons given in Section 5.1.2.

5.2 Low Pressure

5.2.1 LOWEST RECORDED

The lowest atmospheric pressure to which ground military equipment may be subjected is a function primarily of altitude. Army representatives at the 7-8 January 1969 meeting on revising MIL-STD-210A (Sissenwine and Gringorten[51]) indicated 4573 m (15,000 ft) as the probable maximum land elevation where military equipment should operate or be stored. Unfortunately, surface pressure data for such elevations are virtually nonexistent and use must be made of pressure measurements made at these elevations in the free air by balloon-borne sensors. Extremes for 4573 m determined in this manner will probably be conservative; that is, areas of potential military operations with elevations of 4573 m will probably have higher minimum pressures than those which occur at 4573 m away from the surface in the free air.

Richard and Snelling[52] have provided extremes of pressure at 2 km intervals up to 30 km for revising the "atmospheric" section of MIL-STD-210A. They indicated that the minimum observed pressure at 4000 m was 548 mb and at 6000 m, 406 mb. Both of these pressures occurred in January in the Canadian Northwest, although not necessarily at the same time or location. Had these minima occurred at the same place and time, the all-time recorded low pressure at 4573 m would have been near 503 mb (14.85 in., 7.3 lb/in.^{2}). This value should not be too different from any actually recorded low pressure at that height; in fact, using the relation given by Court and Salmela,[53] the lowest "improbable" extreme pressure for 4573 m is 501 mb.

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51. Sissenwine, N., and Gringorten, I.I. (1969) Minutes of DOD Engineering Practice Project MISC-0040 Meeting on Proposed MIL-STD-210B, Climatic Extremes for Military Equipment, 7-8 January 1969, AFCRL, Design Climatology Branch.

52. Richard, O.E., and Snelling, H.J. (1971) Working Paper for the Revision of MIL-STD-210A, "Climatic Extremes for Military Equipment" (1 Km to 30 Km), ETAC 5850, USAF Environmental Applications Center, Washington, D.C.

53. Court, A., and Salmela, H.A. (1963) Improbable weather extremes and measurement needs, Bull. Am. Meteorol. Soc. 44, 9:571-575.

If equipment were to be limited to near sea level operations or storage, then pressure minima would be pressures found in tornadoes. Pressures in the core of such phenomena may be 25 percent lower than surrounding pressures (Court and Salmela[53]). For an existing pressure of 1000 mb, the pressure in a tornado would be 750 mb (22.15 in., 10.88 lb/in.^{2}). Since tornadoes are rare and localized events, a better design criterion may be one based on more widespread, both in space and time, low pressure occurrences. Extreme low pressures can occur in cyclones, especially those of tropical origin. The world's lowest recorded sea level pressure, 877 mb (25.90 in., 12.72 lb/in.^{2}), was estimated in the eye of Typhoon Ida on 24 September 1958 about 600 miles NW of Guam (Court and Salmela[53]).

5.2.2 OPERATIONS

Worldwide air operational low pressure extremes (those equalled or exceeded 1.5, 10, 20 percent of the time at locations above which and at times of the year when lowest pressures are observed) have also been prepared by Richards and Snelling[52] for altitudes up to 30 km at 2 km intervals. Use of these minima to estimate low pressure extremes at land elevations of 4573 m is subject to the same reservations discussed in Section 5.2.1. Using Richards's and Snelling's pressure minima for 4000 and 6000 m, one obtains the following approximate extremes at 4573 m for various risks:

	Low Pressure Extreme		
Percent Extremes	(mb)	(in.)	(lb/in.^{2})
1	508	15.00	7.37
5	514	15.18	7.45
10	520	15.36	7.54
20	527	15.56	7.64

Pressure minima for different risks for elevations near sea level have not been determined.

5.2.3 WITHSTANDING

It is presumed that designing for pressure minima does not present an economic or technological problem. Therefore, lowest all-time estimated pressure of 503 mb (14.85 in., 7.3 lb/ft^2) is recommended for withstanding extremes.

6. DENSITY

Density is not routinely measured, but can be calculated using the gas law; that is, $\rho = P/RT^*$ where ρ is density, P is pressure, R is the gas constant, and T^* virtual temperature.

6.1 High Density

Extremes of high density will occur where temperatures are lowest and pressures highest. To determine reasonable density extremes, one can assume that highest densities have occurred with high pressure extremes or with low temperature extremes. Using the temperature of -46°C (Loewe[49]) that accompanied the 1080 mb high pressure record extreme, one obtains a density of 1.656 kg/m^3. Conservatively assuming that a pressure of 1050 mb accompanied the -90°F low temperature record extreme, one obtains a density of 1.783 kg/m^3. Therefore, high density extremes should be calculated using previously determined low temperature extremes.

6.1.1 HIGHEST RECORDED

As described above, a density of 1.783 kg/m^3 can be assumed for highest recorded.

6.1.2 OPERATIONS

Assuming a pressure of 1050 mb with the 1 percent low temperature extreme of -78°F, one obtains a density of 1.720 kg/m^3 for operations.

6.1.3 WITHSTANDING

The withstanding concept is not applicable to density.

6.2 Low Density

The lowest density to which ground military equipment may be subjected is a function primarily of altitude. As discussed in Section 5.2, the highest altitude contemplated for military operations is 4573 m (15,000 ft). Low density extremes for this and lower elevations are presented in this section.

6.2.1 LOWEST RECORDED

Not available.

6.2.2 OPERATIONS (Cormier[54])

Low air density greatly affects aircraft aerodynamic and engine performance. The density of the air near the ground is especially important in aircraft design

54. Cormier, R.V. (1972) Extremes of Low Atmospheric Density Near the Ground for Elevations up to 15,000 ft for MIL-STD-210B, AFCRL-72-0711, AFSG No. 251.

since the lower the density, the longer the takeoff roll required by fixed-wing aircraft and the less weight a rotary-wing aircraft can lift. Concurrent temperature also has an important secondary effect and is necessary for a thorough analysis of engine performance. Consequently, the USAF Aeronautical Systems Division requested that extremes of low density with concurrent temperature near the ground be included in MIL-STD-210B. Since air density decreases with height, extremes are needed for ground elevations up to the highest elevations contemplated for military operations.

MIL-STD-210A included density extremes for different altitudes, but these were "free-air" values and do not represent the much lower densities which can occur near the ground at corresponding elevations. Nonetheless, designers have wrongly used MIL-STD-210A values or the 1962 U.S. Standard Atmosphere and problems have resulted.

This section, using the study of Cormier,[54] provides values of low density (with concurrent temperature) from the most extreme month in the most extreme area that are equalled or surpassed during 1, 5, 10, and 20 percent of the time for ground elevations to 15,000 ft.

Density is not measured in itself, but can be calculated from coincident observations of temperature, relative humidity, and pressure. Since such coincident observations are not available for many stations, the practice of the USAF Environmental Technical Applications Center (ETAC) has been to estimate the surface-level density extremes from empirical equations developed by Kochanski.[55] These require the monthly mean of daily maximum and minimum temperatures, relative humidity, and pressure. This approach was not used in Cormier's study for two reasons: (1) MIL-STD-210B requires the 1 percent density extreme and the empirical equations provide only the 5, 10, and 20 percent extremes; (2) the equations were developed with data from 15 stations and tested against data from 15 other stations; of these stations, only 3 were from areas having extremely low densities and only one had an elevation above 4000 ft. Therefore, although the equations were shown to provide excellent results for both the development and test samples, their utility for estimating density extremes for areas of the world noted for low density and for elevations up to 15,000 ft was not known.

Consequently, Cormier used actual density distributions to determine the 1, 5, 10, and 20 percent extremes.

Choosing the areas of the world and month with lowest density for elevations to 15,000 ft is not straightforward since surface densities are not routinely calculated and published. However, an examination of the perfect gas law ($\rho = P/RT^*$,

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55. Kochanski, A. (1961) Percentile of Air Density at Station Level, TR153 USAF Air Weather Service, Scott Air Force Base, Illinois.

where ρ is the density, P is pressure, R is the gas constant, and T* is virtual temperature) and knowledge of the magnitudes and the possible percent variation of the variables which determine density, lead to the following reasonable assumption: Density extremes for a given elevation will occur at stations having extremes of high temperature, with low pressure and high humidity being much less important.

Using this assumption, 48 stations representing different hot regions of the world and elevations from 10 to 14,753 ft were selected for study from various climatological tables. For each station, the month having the highest mean daily maximum temperature was selected (when two months had nearly equal temperatures, both were selected). Stations below approximately 5500 ft are generally found in North Africa and the Middle East—above this elevation, in the United States and South America.

For a given station/month, densities were computed from coincident observations of station temperature, pressure, and humidity for each hourly observation available within the period of record. Coincident station pressure when not available was computed from either sea level pressures, 850 mb heights, or 700 mb heights. These computed densities were then ranked, and the low densities equalled or surpassed in 1, 5, 10, and 20 percentiles of the observations for a particular station/month determined. The mean temperature of the observations associated with each of these percentiles at each station was then computed. For example, if the 1 percentile density at a particular location is equal to A, and five observations had density values equal to A, then the associated mean temperature value would be the mean temperature of the five observations with a density value of A.

The 1, 5, 10, and 20 percentile densities for each station/month and associated mean temperatures were plotted as a function of station elevation and examined for internal consistency. This examination indicated that densities from nine stations appeared to be grossly too low. Before rejecting these outright, the 5, 10, and 20 percentile densities were compared with estimates of these same percentile computed using the empirical estimating equations. These comparisons confirmed the original appraisal, and the stations were excluded from further analysis. Six of the nine indicate an average of less than two observations per day; this would account for the bias toward lower than reasonable densities if the one observation were taken near midday. No reasons for the low densities are apparent at the three remaining stations; perhaps computational and/or coding errors were involved.

Rather than plot density versus elevation to determine the worldwide envelope for the 1, 5, 10, and 20 percentile density extremes for the remaining 39 stations, the percentile densities at each station were converted to and plotted in terms of

percent departure from the 1962 standard density found in the altitude corresponding to the station elevation. This was done because the magnitude of the normal decrease of density with altitude tends to mask the variation of density extremes with height.

Figure 18 contains a plot of the 1 percentile densities for the 39 stations. Also included on Figure 18 is a quasi-envelope for these values with two points falling outside of the envelope. However, the envelope was drawn within the purpose and philosophy of MIL-STD-210B of finding worldwide extremes that are generally "representative" of an area or condition rather than anomalies. The envelope as drawn fulfills that function and is recommended.

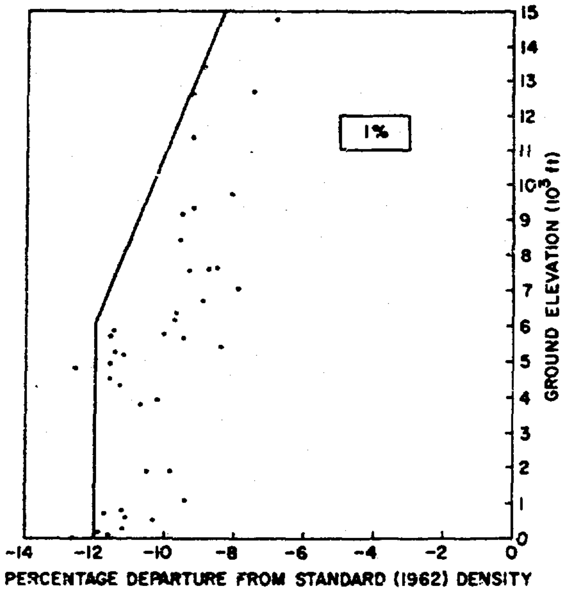
It is recognized that other locations and/or months might be uncovered that could conceivably alter the envelope, but such a change would be small since the sample of data used is quite representative of the near-ground, extreme low densities over the world. The envelope was not drawn independently of the other percentiles. Similar point plots for the 5, 10, and 20 percentiles were constructed and examined collectively, and then the envelopes were drawn. The recommended percentile curve shows a density that is 12 percent below standard from sea level to 6000 ft. This negative departure then decreases linearly with ground elevations approximately 0.4 percent per 1000 ft up to 15,000 ft.

Figure 19 is a composite figure presenting the 1, 5, 10, and 20 percentile worldwide "worst" area and month, low density extremes for elevations to 15,000 ft for MIL-STD-210B. The 5, 10, and 20 percentile envelopes have shapes similar to the 1 percentile envelope. The 5 percentile curve shows a constant -11.5 percent departure from standard density up to 6000 ft, the 10 percentile curve a constant -11.0 percent, and the 20 percentile curve a constant -10.5 percent.

Figure 20 is the companion plot for the mean temperature associated with the 1, 5, 10, and 20 percentiles of density. These curves show an increase of lapse rate with height at lower elevations and a lapse rate which approaches $4^{o}F$ per 1000 ft at higher elevations.

6.2.3 WITHSTANDING

The withstanding concept is not applicable to extremes of low density at various surface altitudes since no possible damage is foreseen.



ELEVATION (ft)	STATION
10	ABADAN, IRAN
112	BAGHDAD, IRAQ
184	KUWAIT, ARABIA
318	ALLAHABAD, INDIA
492	QUARGIA, ALGERIA
656	ASWAN, EGYPT
663	KANAQUIN, IRAQ
817	KARIMA, SUDAN
1079	BAMAKO, MALI
1883	EL OBEID, SUDAN
1900	FES-SAIS, MOROCCO
3773	TORREON, MEXICO
3950	TEHRAN, IRAN
4331	KERMANSHAH, IRAN
4521	ZAHEDAN, IRAN
4685	CHIHUAHUA, MEXICO
4856	DROSH, PAKISTAN
4938	SHIRAZ, IRAN
5200	SPRINAGAH, KASHMIR
5240	ESFAHAN, IRAN
5459	IFRANE, MOROCCO
5735	KERMAN, IRAN
5761	TRINIDAD, COLO, USA
5869	KABUL, AFGHANISTAN
6172	COLORADO SPGS, COLO, USA
6352	RATON, N. MEX, USA
6719	FLOURET, KENYA
7016	FORT BRIDGER, WYO, USA
7535	ALAMOSA, N. MEX, USA
7586	BRYCE CANYON, UTAH, USA
7628	ASMARA, ETHIOPIA
8432	COCHABAMBA, BOLIVIA
9226	QUITO, ECUADOR
9350	SUCRE, BOLIVIA
9731	IPALES, COLOMBIA
11,348	LA QUIACA, ARGENTINA
12,546	JULIACA, PERU
13,350	LA PAZ, BOLIVIA
14,753	CERRO, PERU

Figure 18. One-Percent Low Densities (Extreme Month) for Listed Stations (to ≈ 15,000 ft) and the Envelope of These Densities

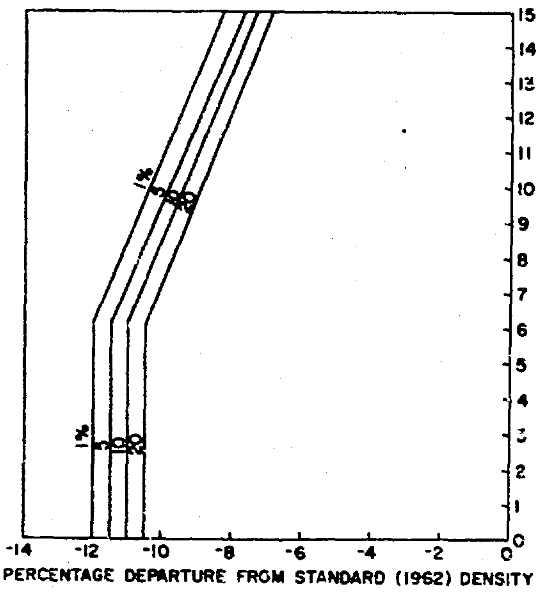


Figure 19. Low Density Extremes—1, 5, 10, and 20 Percent—for Ground Elevations to 15,000 ft

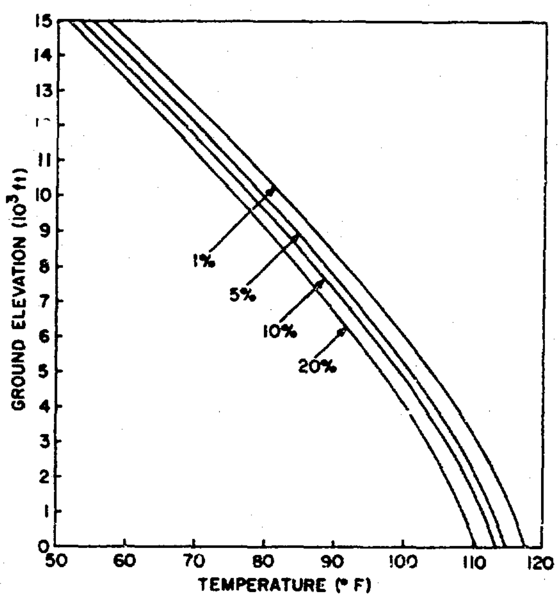


Figure 20. Mean Temperatures Associated With the 1, 5, 10, and 20 Percent Density Extreme for Ground Elevations to 15,000 ft

7. OZONE CONCENTRATION

Ozone concentration extremes at the ground were estimated by extrapolating to zero elevation the curve provided by Kantor,[56] Figure 30, in Section IV. 1. 7.

7.1 Highest Recorded

A value of 325 $\mu g/m^3$.

7.2 Operations

A value of 220 $\mu gm/m^3$.

7.3 Withstanding

Not Available.

8. SAND AND DUST

Extremes of sand/dust likely to be encountered by military equipment are not those of nature, but rather those caused by heavy traffic over dry dirt roads (Gringorten and Sissenwine[57]). Such extremes are not true climatic extremes and as such do not belong in MIL-STD-210A or a revision thereof. However, design for these elements is extremely important and since extremes of these elements for design purposes will probably not appear elsewhere, it was decided (Gringorten and Sissenwine[57]) to present most logical extremes of these elements in MIL-STD-210B. The information that follows was prepared by Blackford and McPhilimy[58] as amended by McPhilimy[59].

Practically all military materiel is subject to some damage from sand and dust. The types of damage can be categorized in three major groups: (1) abrasive damage, (2) clogging and blocking, and (3) promotion of corrosion and the growth of fungi.

Abrasive damage is particularly important in internal combustion engines where dust particles caught between any moving parts exert a cutting action.

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56. Kantor, A.J. (1972b) Ozone Density Envelopes up to 30 km for MIL-STD-210B, AFCRL (LKI) INAP No. 96.

57. Gringorten, I.I., and Sissenwine, N. (1969) Minutes of DOD Standardization Project MISC-0597 Meeting on Proposed MIL-STD-210B, Climatic Extremes for Military Equipment, 13-14 October 1969, AFCRL, Design Climatology Branch.

58. Blackford, P.A., and McPhilimy, H.S. (1972) Sand and Dust Considerations in the Design of Military Equipment, ETL-TR-72-7, U.S. Army Engineer Topographic Laboratories, Fort Belvoir, Virginia.

59. McPhilimy, H.S. (1973) Recommended Changes to MIL-STD-210B (4th Draft), U.S. Army Engineer Topographic Laboratories, Fort Belvoir, Virginia.

Abrasive action is not limited to internal moving parts, but is also important to exposed components such as propeller blades and various kinds of linkages. Corrosion and fungus growth are promoted when abrasion destroys protective coatings. Clogging and blocking by sand/dust may cause many kinds of electrical failures and inoperation of certain kinds of equipment such as pitot tubes.

8.1 Differentiating Sand and Dust

Sand and dust are terms for small-sized particles of matter found on the earth's surface. They are usually differentiated from one another by means of differences in size, although the terms are often used loosely and sometimes interchangeably. Drawing a distinction between the two is difficult, since the particles sizes involved grade into one another, and any boundary size used for distinguishing between them will be somewhat arbitrary at best. Nevertheless, there are differences in the physical characteristics and in the military effects of sand and dust that make the attempt worthwhile to continue a distinction. Four important differences in the behavior of grains of the same material and the same shape have been suggested. These differences, a function of particle size alone, are: (1) there is a critical diameter for which the threshold wind—that wind just necessary to pick the particles off the ground—is a minimum; as the particle diameters increase or decrease from this size, stronger wind pressures are required to move the grains; (2) smaller particles tend to be maintained aloft indefinitely by eddy currents of normal winds; (3) smaller particles tend to collect moisture and become bound together; and (4) smaller particles, even though angular, begin to feel smooth when rubbed between the fingers. These behavioral changes take place in the narrow size range between 70 and 150 μm.

Although boundary sizes between sand and dust have been used in the past in various military and other documents, there has been no consistency and sometimes no apparent logic in their selection. For convenience, and because there is a need for some standardization in the definition, it is suggested that the distinction between sand and dust be based on particle size alone, and that the boundary value approximate the point at which the behavioral changes noted above occur.

It is recommended that dust be defined as all particulate matter up to 150 μm in size. Sand is defined as solid, noncohesive, particulate matter in the size range of 150 to 1,000 μm; organic matter in this size range is of little significance to materiel testing and may be disregarded so long as it is not present in such quantities as to significantly dilute the sands used for testing.

8.2 Characteristics and Behavior of Sand

For most military considerations, angularity and hardness are the most important characteristics of sand grains. Hardness, in turn, is a function of the

mineral composition of the particles. It turns out that, on a worldwise basis, most sands are composed of quartz (SiO_2), which is one of the very common rock-forming minerals. Many of the common forms of sand have a hardness of 7 on the Mohs scale, which is hard enough to cause abrasive damage to most forms of steel.

Whether most sand grains are rounded or angular may be a matter for some conjecture, but there can be little doubt that a substantial proportion have an angular shape. Even though quartz particles found in desert areas may have been rounded by water action at some time, they may well have become angular again through impact action and their tendency to fracture conchoidally.

Because sand in its large accumulations tends to exist in a general fixed size range of 100 to 1,000 μm, its behavior under wind pressure is qualitatively fairly well-defined and predictable. At some threshold windspeed, which depends on the roughness of the ground surface and the size of the grains, sand grains begin to move in the direction of the wind. As the particles move, they impact on other grains and bounce off or move the impacted grains, or both, so that there is soon a mass of moving sand particles, which appear to the observer to be suspended indefinitely in the air. In fact, however, each sand grain moves in a rather flat and relatively short trajectory, after which it falls to the ground and bounces again into the air or moves other grains into similar paths. In general, the sand is confined to the air layer within the first meter above the ground. Within this layer, about half the sand grains (by weight) move within the first 10 mm above the surface and most of the other half are within the first 100 mm.

As a consequence of the low elevation at which most sand grains move, most abrasive damage caused by the sand is at or near ground level. Nevertheless, the smaller number of grains at the relatively high levels can be effective in removing paint from various surfaces as well as causing severe erosion to exposed materials, particularly glass and plastics.

The quantitative relationship between sand movement and meteorological windspeeds is not well established and because of the large number of variables, only a few generalizations can reasonably be made. In desert areas, such as the Sahara where there are large accumulations of almost pure sand, one tends to encounter sandstorms in which visibility at normal eye level is virtually unrestricted after the small dust fraction initially present has been carried away. In most dry areas, however, there is so much dust on the surface that most strong winds result in dust storms rather than sand storms. It has been estimated that the wind required to move dry loose sand particles is on the order of 18 mph at a height of 5 ft above the ground. This corresponds to a wind of about 20 mph at a height of 10 ft. The height for which windspeeds exceeded 1, 2 1/2, 5, 10, and 20 percent of the time over North America are mapped in the Handbook of Geophysics.[10] These maps show that at 10 ft, winds of at least 20 mph can be expected 1 percent of the

time over the midlatitude desert areas. Thus, we can expect sand storms with winds of about 18 mph at 5 ft, at least 1 percent of the hours at some desert stations. Durations of such storms when they occur are highly variable, ranging from an hour or two, to two or three days.

There are vast sandy areas in the Sahara and in Saudi Arabia, as well as significant areas in most of the world's deserts. Borders of continents also have sandy beaches of varying width, and there are large sand deposits at or near the surface in many inland areas formerly covered by water.

8.3 Characteristics and Behavior of Dust

In contrast to the area distribution patterns that can be associated with sand, dust particles—because of their low terminal velocity—can remain suspended in air indefinitely and settle to the surface anywhere. Consequently, dust and its associated problems may be found anywhere although there are differences in degree from place to place.

Although surface soils from most areas contain enough fine materials to be the source of airborne dust, the actual occurrence of airborne dust depends on many interrelated factors. These are:

(1) the state of agglomeration of the surface particles;

(2) the presence or absence of protective cover whether natural or man-made;

(3) the relative humidity (since dust is hygroscopic, the lower the humidity, the greater the problem);

(4) the windspeed (because of its drying action and its ability to circulate dust);

(5) the temperature (since evidence indicates that the higher the temperature, the greater the dust problem).

Precipitation is of considerable importance in determining the state of agglomeration of particles, since low soil moisture is a primary deagglomerative factor. Excluding Antarctica, over 40 percent of the world's surface is classified as moisture deficient, so that these areas would be expected to produce dust problems. What is less obvious, however, is that even in high moisture areas, when protective cover is removed, there are periods when the soil dries out to an extent that dust problems become severe.

The factors listed above all are important in determining natural dust potential, even though the effects are known only in a qualitative sense. Nevertheless, the most important deagglomerating factor, except when the surface is completely wet, is man himself, especially when he is armed with machinery to increase his speed and mobility. Tanks, trucks, bulldozers, artillery, aircraft, and even marching troops are very efficient in the destruction of protective cover and the separation of small particles, so much so that dust problems must be expected

anywhere these activities take place. Possible exceptions are those places under permanent snow, ice, or water cover, or those rare places that have precipitation so often that the surface never dries out.

There is considerable difficulty in accurately determining the size spectrum of dust, and measurements made by different methods are seldom in close agreement. Therefore, it is difficult to generalize about predominant dust sizes. One source indicates that the predominant sizes of dust particles will be between 0.1 and 2 μm. Other measurements taken from dust plumes around operating tanks at Yuma Proving Ground indicate a maximum size somewhat smaller than 74 μm, and more than 80 percent of the particles (by weight) larger than 5 μm. It is fair to state, however, that the higher the sampling location is above the ground, the smaller the particles, since larger sizes tend to settle out the fastest.

There is likewise a wide variability in concentrations of dust suspended in the air. This variability within a seemingly uniform micro-environment is illustrated by a series of nine dust samples collected next to a bulldozer backfilling a trench with dry earth. All samples were collected within a time span of 1 hr and care was taken to get as nearly identical conditions as possible, yet the concentrations varied from 0.26 to 5.19 mg/ft^3 (9 to 183 mg/m^3). Most of the pertinent data available regarding measured dust concentrations are incorporated in Table 25.

8.4 Design and Test Considerations

Translation of sand and dust information into reasonable design and test criteria is difficult because many widely differing opinions can be supported by the available data. Section 8.5 below contains specific recommendations for changing the criteria now specified in MIL-STD-210A, but some explanation of the reasons behind these changes and of the manner in which they should be applied is in order. The discussion is based on the premise that dust is always present in varying amounts and is, therefore, something to be considered in all design problems. This assumption is not strictly true, since there may be equipment designed for use only in dust-free environments, but this is not a general consideration. From the information presented so far, one can conceive of three different levels of dust exposure that might apply to nearly all military materiel.

One of these levels describes a situation in which certain items might be used in socially remote areas and not in association with normal military or other dust conducive activities, so that only "natural" dust concentrations need be considered. Only dust picked up and transported by wind from dry loose surfaces will be critical.

Table 25. Dust Concentrations Under Various Field Conditions (Blackford and McPhilimy[58])

Activity or Event	Type of Surface	Concentration (mg/ft^3)	Concentration (mg/m^3)
Dust storm in Australia			
500 ft above ground	Dry surface; little protective cover.	0.06	2.1
1,000 ft above ground	Wind: 24 to 30 mph	0.5	17.6
2,000 ft above ground	Ground visibility: 1,000 ft.	0.2	7.1
3,000 ft above ground		0.05	1.8
4,000 ft above ground		0.02	0.7
Wind 12 to 14 mph	Scrub covered field; no activity	0.4	14.1
Fresh breeze: 19 to 24 mph	Unpaved sandy area; no disturbing activity	1.7	60.0
Severe storm; not defined	Dry surface; no cover	5.0	176.0
Troops drilling	Dry parade ground	0.9	31.8
Troops marching	Dry unpaved road	2.0	70.6
One Staff car	Unpaved maneuver road	2.9	102.4
Convoy of trucks and towed guns	Unpaved maneuver road	5.1	180.0
Column of tanks	Bare, dry, sand and dust surface; measured beside column	7.3	257.5
Muzzle blast from gun on M-60 Tank	Bare, dry surgace; measured approx. 65 ft away	1.3	45.9
MON61-A Drones; one JATO Bottle	Hard packed sand and gravel; two separate measurements	0.9 2.4	31.8 84.7
Half-track in operation	Loose sand; measured 30 ft away	29.2	1030.8
One Tank—10 mph	Heavy dust surface	27.2	960.2
Column of 6 Light Tanks	Moving into wind over heavy dust surface	53.5	1888.6
Engine compartment in Tank		170.0	6001.0
Aircraft taking off	Clean, paved runway	0.8	28.2
H-21 Helicopter	Over freshly plowed fields		
During take-off		40.0	1412.0
Hovering at 1 ft		15.5	547.2
Hovering at 10 ft		18.1	638.9
Hovering at 75 ft		7.3	257.7
Hovering with second helicopter maneuvering nearby		64.0	2259.2

A second situation, which may be considered normal, is one in which the mere fact of military presence creates environmental problems ranging from mud to dust, depending largely on the moisture content of the surface soil. As has been shown, this is the situation that must be considered realistic for most materiel, even though it is considerably more severe than natural dust storms.

A third category might best be established for the special conditions associated with aircraft operations, particularly helicopters. These conditions, which generally are the most severe that have been measured, should be used to apply to those items normally used in and around helicopters.

Design specifications nearly always have testing implications, so that some thought needs to be given to testing for dust and sand. The present dust test found in Method 510 of MIL-STD 810B (Department of Defense[60]), may be nearly adequate for the second situation described above. The test specifies concentrations of 300 ± 200 mg/ft^3 (10.6 ± 7.1 gm/m^3), which is somewhat higher than most concentrations measured in the field. One possible weakness of Method 510 is the fact that the specified dust is at least 97 percent quartz, whereas there is the possibility that significant quantities of other and harder minerals, such as corundum, may be part of dust in the field. The whole question of dust composition on a world scale however, is one that has yet to be solved, and there remains little evidence on which to base a change that would require specific quantities of other minerals. Another potential weakness of Method 510, depending on the purpose for which the tests are conducted, is that the test dust may be recirculated repeatedly through the chamber, with the distinct possibility that its size distribution and particle shape will change drastically even after one pass.

For testing against the severe dust condition, it would appear that the techniques developed for sampling dust in the rotor downwash of helicopters might be the most practical. That is, use a helicopter over a prepared dry surface, keeping the conditions as standard as possible even though they are not completely controlled.

So far, the subject of design and testing specifically for sand has been ignored, but with some reason. For one thing, if penetration into small openings is the problem under consideration, the seals or openings that will exclude moderate-sized dust will also exclude sand. If the question is one of resistance to abrasion, this can be tested in many cases by using small samples of the materials from military equipments. For large items, a wind tunnel capable of simulating the natural phenomenon of blowing sand would be ideal, but difficult and expensive to construct. As an alternative, one could expose such items in

60. Department of Defense (1967) Military Standard Environmental Test Methods, MIL-STD-810B, 15 June 1967, Aeronautical Systems Division, Wright-Patterson AFB, Ohio.

a testing procedure similar to that suggested for severe dust conditions, but over a surface that is composed largely of loose sand.

8.5 Recommended Sand/Dust Extremes

8.5.1 HIGHEST RECORDED

Insufficient reliable and systematic measurements have been made to establish an extreme value. However, concentrations as high as 6.00 gm/m^3 (3.75×10^{-4} lb/ft^3) (particles smaller than 74 μm) have been measured inside the engine compartment of a tank moving over a very dusty surface.

8.5.2 OPERATIONS

Three operational levels are recommended; selection of the appropriate one depends on intended use of the materiel under consideration.

(1) Items likely to be used in close proximity to aircraft operating over unpaved surfaces should be designed for particle concentrations of about 2.19 gm/m^3 (1.32×10^{-4} lb/ft^3) in multidirectional strong winds (downwash from helicopter rotors). Such particles range in size up to 500 μm (1.97×10^{-2} in.) in diameter.

(2) Items never used or never exposed in close proximity to operating aircraft, but which may be found near operating surface vehicles, should be designed for particle concentrations of 1.06 gm/m^3 (6.61×10^{-5} lb/ft^3) with windspeeds up to 18 mps (59 fps) at a height of 3 m (10 ft). Particle sizes will range from less than 74 μm (2.91×10^{-3} in.) in diameter to 1000 μm (39.3×10^{-3} in.) with the bulk of the particles ranging in size between 74 and 350 μm (13.8×10^{-3} in.).

(3) The two categories, above, are likely to include most military items. However, items that are assured of being subjected only to natural conditions should be designed for particle concentrations of 0.177 gm/m^3 (1.10×10^{-5} lb/ft^3) with windspeeds of 18 mps (59 fps) at a height of 3 m (10 ft). Under these conditions, the bulk of the particle sizes are likely to be less than 150 μm (5.90×10^{-3} in.), except that some larger particles (up to 1000 μm) may be in motion within several feet above the ground.

In all categories, temperatures are typically above 21°C (70°F) and humidities less than 30 percent. For testing purposes, particle sizes up to 150 μm should be used if the primary concern is with the penetration of fine particles. If the abrasion effect of blowing sand is the primary concern, particle sizes up to 1000 μm should be used, but the bulk of the particle should be between 150 and 500 μm.

8.5.3 WITHSTANDING

Not available.

III. Extremes for Naval Surface and Air Environment

Information presented in this section is based on reports prepared by staff members of the National Climatic Center for the U.S. Navy, the department responsible for providing climatic extremes for the Naval environment. They studied extremes* in both coastal port locations and over the open ocean, and the working paper that they prepared[7] lists separate sets of surface extremes for each of these two areas. Design of equipment destined for surface use in a maritime environment should be based on the extreme of these two surface maritime environments. Therefore only one set of surface extremes, either from coastal ports or the open sea, is recommended in this document for adoption in MIL-STD-210B.

The basic premise applied to the selection of extremes of climatic elements was that they should be representative of extremes from the most severe area and the most severe month.

The Marsden Square geographic system (10° latitude by 10° longitude areas) generally is used to refer to locations over the open ocean. Figure 21 gives the locations of the numbered Marsden squares.

Measurements of meteorological elements made aboard ship are not taken at a standard height, and it is usually impossible to tell from the data at which height

*Extremes which would be encountered by ships involved in icebreaking operations were not studied.

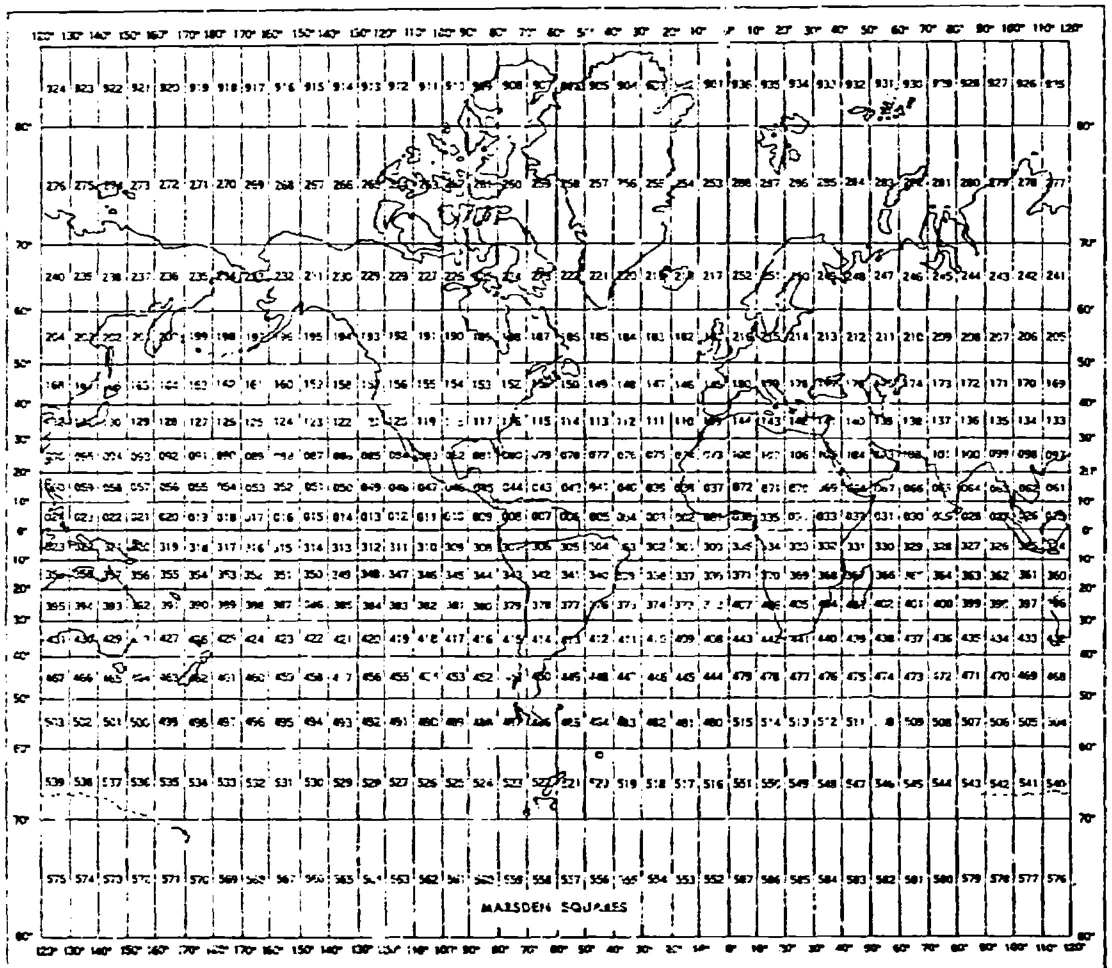

Figure 21. Marsden Square Locations

above the sea surface they were taken. The assumption was therefore made that all measurements were taken at the same height and the data were used as if they were homogeneous.

Operational extremes are presented for four probabilities: 1, 5, 10, and 20 percent. Based on guidance from the Office of the Assistant Secretary of Defense (Joint Chiefs of Staff, 1969), emphasis is placed on the 1 percent extreme. For this extreme, an average diurnal curve is shown where applicable. It is based on days during which the 1 percent extreme occurred. In addition to the diurnal curve for the element given, diurnal curves for other selected elements are included.

The diurnal curves for insolation were derived using an empirical relation between insolation and observed cloudiness (or absence thereof). In most cases, insolation curves accompanying extremes are for clear sky conditions.

Withstanding extremes presented only for surface equipment are for estimated durations of exposure of 2, 5, 10, and 25 years. These values are for a 10 percent risk in accordance with guidance received.

I. NAVAL SURFACE ENVIRONMENT

1.1 Temperature

1.1.1 HIGH TEMPERATURE

See Section II. 1. 1 for a discussion of temperatures attained by equipment exposed to a hot environment.

1.1.1.1 Highest Recorded

The highest temperature recorded was not explicitly given by Crutcher et al.[7] Data points plotted by Crutcher et al in Figure 23 show 123°F as the highest recorded.

1.1.1.2 Operations

U.S. Navy climatological publications were screened to determine maritime areas of the world and the months where maximum temperatures occur. This study showed that maximum maritime temperatures occur in Persian Gulf ports. The river port of Abadan, Iran which is accessible to ocean going traffic is typical of such locations. Because of the availability of seven years of data from this location, it was chosen for analysis.

From a listing of the hourly temperatures from Abadan for the warmest month, the 1, 5, 10, and 20 percent high temperature extremes were determined. These are:

Percent Extreme	Temperature (°F)
1	119
5	114
10	113
20	110

To provide a typical diurnal circle associated with the 1 percent extreme high temperature, hourly values of temperature on the dates during the period of record when the 1 percent value, 119°F, was equalled or exceeded were determined and averaged by hour. In addition to the temperature, average hourly values of concurrent relative humidity and insolation were also determined. This information is graphically portrayed in Figure 22. The 1 percent high temperature extreme occurs at 1500 local time and the minimum temperature associated with the high extreme is 84°F, occurring at 0600 local time. Associated with the 119°F extreme is a relative humidity of near 20 percent and an insolation of 95 langleys/hr (350 BTU/ft^2/hr). This same information, along with cycles for 5, 10, and 20 percent extremes is presented in tabular format in Table 26. (The extreme temperatures at 1500 local time (LT) in the table and in Figure 22 are average values based on all days on which the previously determined 1, 5, 10, and 20 percent extremes were equalled or exceeded; these temperatures therefore may be a few tenths of a degree greater than the previously quoted 1, 5, 10, and 20 percent extremes.)

Crutcher et al[7] did not provide wind speeds associated with the high temperature cycle. From an examination of wind roses for 0600 and 1500 LST from Abadan, one can see that assuming a constant 3 mps wind speed for 24 hr during high temperature episodes is a reasonable assumption.

1.1.1.3 Withstanding

The port of Abadan was chosen to determine the 10 percent high temperature withstanding extreme. This decision was based on the climate at Abadan and the data record available. Yearly maximum temperatures were obtained from the following publications: For the period 1938-1948, Persian Gulf to the Mediterranean Meteorological Data; 1949-1955, Card Deck 166, NWRC; 1958-1967, Monthly Weather Summary for Synoptic Stations; and 1968, Iranian Oil Operating Companies, Monthly Weather Bulletin (all on file at the National Climatic Center, Asheville, North Carolina).

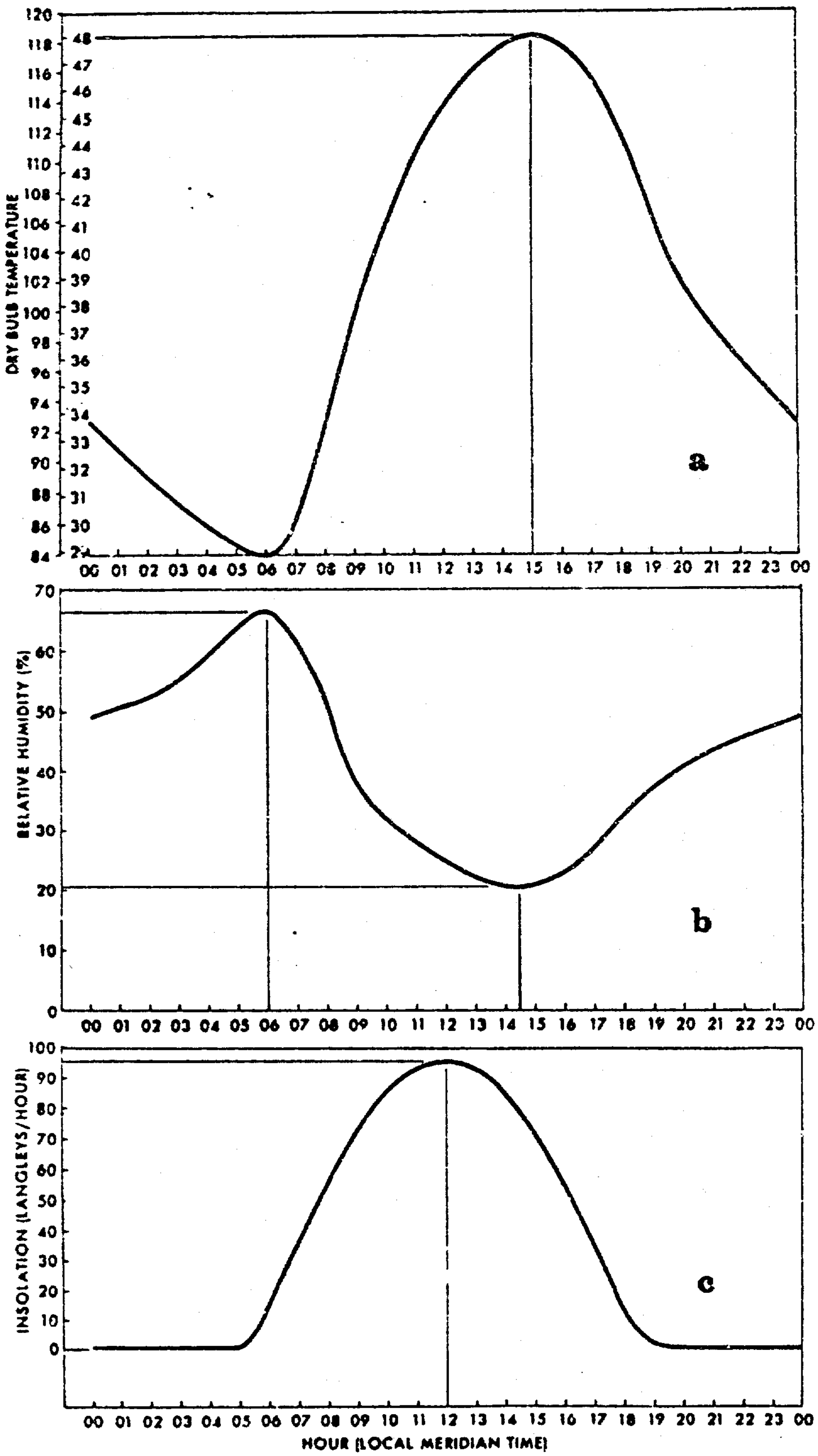

Figure 22. Diurnal Cycle of Average (a) Temperature, (b) Relative Humidity, and (c) Insolation, Associated with the 1 Percent High Temperature Extreme (118°F) for the Naval Surface Environment

Table 26. Diurnal Cycles of Average Temperature, Relative Humidity and Insolation Associated With Extremes of a High Temperature in the Naval Surface Environment

HOUR LOCAL MEAN TIME

ELEMENT		00	01	02	03	04	05	06	07	08	09	10	11	12	13	14	15	16	17	18	19	20	21	22	23	00
AIR TEMPERATURE	°F	92.6	90.6	89.0	87.3	86.0	84.6	83.9	86.3	[illegible]	99.8	105.4	110.1	[illegible]	116.0	117.6	118.5	117.7	115.4	112.1	106.9	103.4	99.3	96.8	94.7	92.6
	°C	33.7	32.7	31.7	30.7	30.0	29.2	28.8	30.2	33.4	37.7	40.8	43.3	45.4	46.7	47.6	48.1	47.6	46.3	44.5	41.6	39.1	37.4	36.0	34.8	33.7
RELATIVE HUMIDITY	%	46.0	50.7	52.5	55.3	58.5	64.2	66.6	59.9	50.5	37.5	31.8	27.8	24.7	22.1	20.5	21.1	22.9	26.9	32.5	37.9	40.7	43.3	45.4	47.2	48.0
INSOLATION	LY/HR	00	00	00	00	00	00	16	36	56	73	85	92	95	92	83	70	53	33	13	01	00	00	00	00	00

(a) 1% Extreme

HOUR LOCAL MEAN TIME

ELEMENT		00	01	02	03	04	05	06	07	08	09	10	11	12	13	14	15	16	17	18	19	20	21	22	23	00
AIR TEMPERATURE	°F	92.0	90.1	88.8	87.1	85.6	84.1	82.9	84.3	89.9	96.5	102.4	107.2	110.2	112.2	113.7	114.5	114.0	112.5	109.7	105.4	100.7	97.7	95.3	93.4	92.0
	°C	33.3	32.4	31.6	30.6	29.8	28.9	28.3	29.1	32.2	35.8	39.1	41.8	43.4	44.6	45.4	45.8	45.6	44.7	43.2	40.8	38.2	36.5	35.2	34.1	33.3
RELATIVE HUMIDITY	%	46.6	44.3	48.9	51.7	53.8	56.0	57.4	55.7	48.7	38.5	34.2	27.6	24.0	21.7	20.4	20.3	21.4	23.9	28.3	33.2	37.7	41.6	43.1	44.9	46.6
INSOLATION	LY/HR	00	00	00	00	00	00	16	36	56	73	85	92	95	92	83	70	53	32	12	01	00	00	00	00	00

(b) 5% Extreme

HOUR LOCAL MEAN TIME

ELEMENT		00	01	02	03	04	05	06	07	08	09	10	11	12	13	14	15	16	17	18	19	20	21	22	23	00
AIR TEMPERATURE	°F	91.5	90.1	88.6	87.1	85.6	84.1	82.6	82.5	87.5	94.2	100.5	105.0	108.7	111.3	112.6	113.4	113.0	111.5	108.8	104.2	98.9	95.9	94.1	92.8	91.5
	°C	33.1	32.3	31.4	30.6	29.8	28.9	28.1	28.1	30.8	34.6	38.1	40.6	42.6	44.1	44.8	45.2	45.0	44.2	42.7	40.1	37.2	35.5	34.5	33.8	33.1
RELATIVE HUMIDITY	%	45.5	46.4	47.8	49.3	50.5	52.0	53.2	52.2	46.6	37.8	32.5	26.6	23.4	21.5	20.5	20.0	20.2	21.8	25.6	30.6	35.5	38.7	42.6	44.0	45.3
INSOLATION	LY/HR	00	00	00	00	00	00	16	36	56	73	85	92	95	92	83	70	53	33	12	01	00	00	00	00	00

(c) 10% Extreme

HOUR LOCAL MEAN TIME

ELEMENT		00	01	02	03	04	05	06	07	08	09	10	11	12	13	14	15	16	17	18	19	20	21	22	23	00
AIR TEMPERATURE	°F	90.7	89.2	87.7	86.1	84.6	82.9	81.3	81.0	84.1	89.7	95.4	100.3	104.2	107.7	109.7	110.3	109.3	107.5	104.8	101.2	97.3	94.5	93.4	92.2	90.7
	°C	32.6	31.8	30.9	30.1	29.2	28.3	27.4	27.2	28.9	32.1	35.2	37.9	40.1	42.1	43.2	43.5	42.9	41.9	40.4	38.4	36.3	34.5	34.1	33.4	32.6
RELATIVE HUMIDITY	%	41.5	42.7	44.1	45.3	46.2	47.3	47.6	45.3	42.8	37.3	32.2	27.3	23.7	21.2	19.7	19.4	19.7	21.9	25.6	29.4	33.0	36.2	37.7	40.5	41.5
INSOLATION	LY/HR	00	00	00	00	00	00	16	36	56	73	85	92	95	92	83	70	53	32	12	01	00	00	00	00	00

(d) 20% Extreme

The maximum temperature for each year was plotted on semilogarithmic normal probability paper and a confidence envelope was drawn according to a procedure developed by Gringorten.[61] This confidence envelope consists of two lines between which should lie 95 percent of all annual extremes; 2-1/2 percent of all annual extremes will be outside the 0.975 (97.5 percent) line on the high side and 2-1/2 percent will be outside the 0.025 (2.5 percent) line on the low side. With the confidence envelope as a guide, the median line for a normal distribution with the same mean and standard deviation as the yearly extreme sample was drawn to represent a line of best fit. This information is shown in Figure 23. As discussed in Section I.2.4, using Figure 23, the withstanding high temperature 10 percent extremes for EDE's of 2, 5, 10, and 25 years are:

EDE (Years)	Temperature
2	123.2
5	124.0
10	124.3
25	124.8

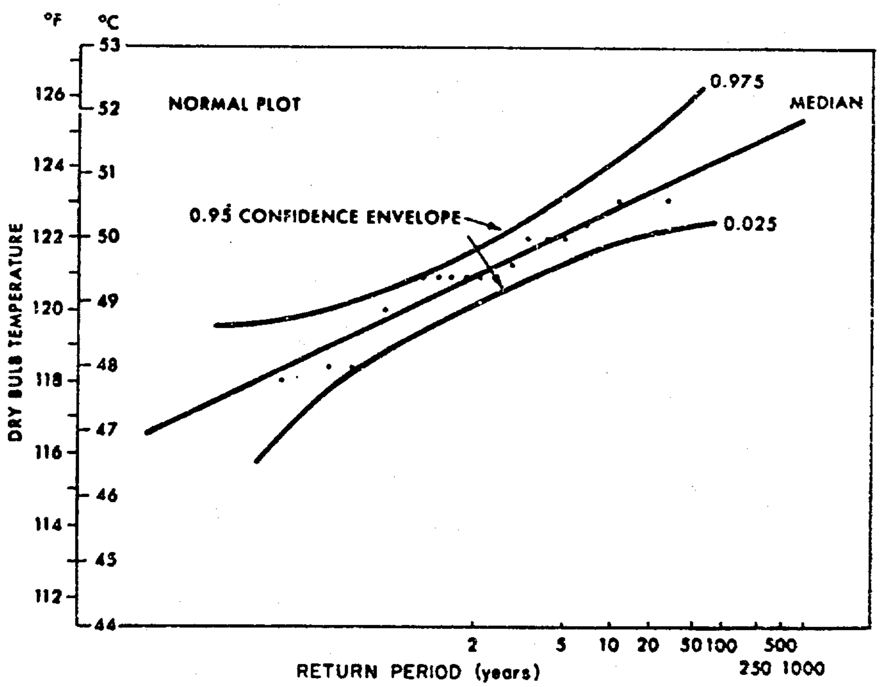

Figure 23. Naval Surface Environment, Expected Annual Maximum Temperature

61. Gringorten, I.I. (1963b) Envelopes for ordered observations applied to meteorological extremes, J. Geophys. Res. 68:3.

Crutcher et al[7] did not provide cycles to accompany the withstanding extremes. As a first approximation, the 1 percent cycle with cycles of accompanying elements, Table 26, adjusted upwards at each hour for the difference between the 1 percent operational extreme and the 10 percent withstanding extremes is recommended. That is, the following increments (°F) should be added to the temperatures given in Table 26 to provide the withstanding extreme cycles.

EDE (Years)	Temperature Increment (°F)
2	5
5	6
10	6
25	7

For associated windspeed see Section 1.1.1.2.

1.1.2 LOW TEMPERATURE

See Section II.1.2 for a discussion of cold extremes.

1.1.2.1 Lowest Observed

The lowest temperature recorded was not explicitly given by Crutcher et al.[7] Data points plotted by Crutcher et al in Figure 24 do not go below -37°F.

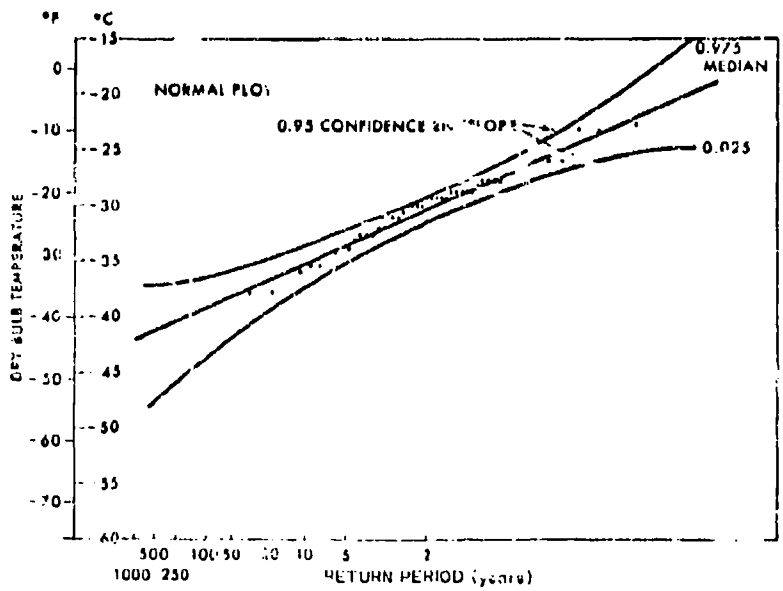

Figure 24. Naval Surface Environment, Expected Annual Minimum Temperature

Crutcher et al[7] did not provide cycles to accompany the withstanding extremes. As a first approximation, the 1 percent cycle with cycles of accompanying elements, Table 26, adjusted upwards at each hour for the difference between the 1 percent operational extreme and the 10 percent withstanding extremes is recommended. That is, the following increments (°F) should be added to the temperatures given in Table 26 to provide the withstanding extreme cycles.

EDE (Years)	Temperature Increment (°F)
2	5
5	6
10	6
25	7

For associated windspeed see Section 1. 1. 1. 2.

1. 1. 2 LOW TEMPERATURE

See Section II. 1. 2 for a discussion of cold extremes.

1. 1. 2. 1 Lowest Observed

The lowest temperature recorded was not explicitly given by Crutcher et al.[7] Data points plotted by Crutcher et al in Figure 24 do not go below -37°F.

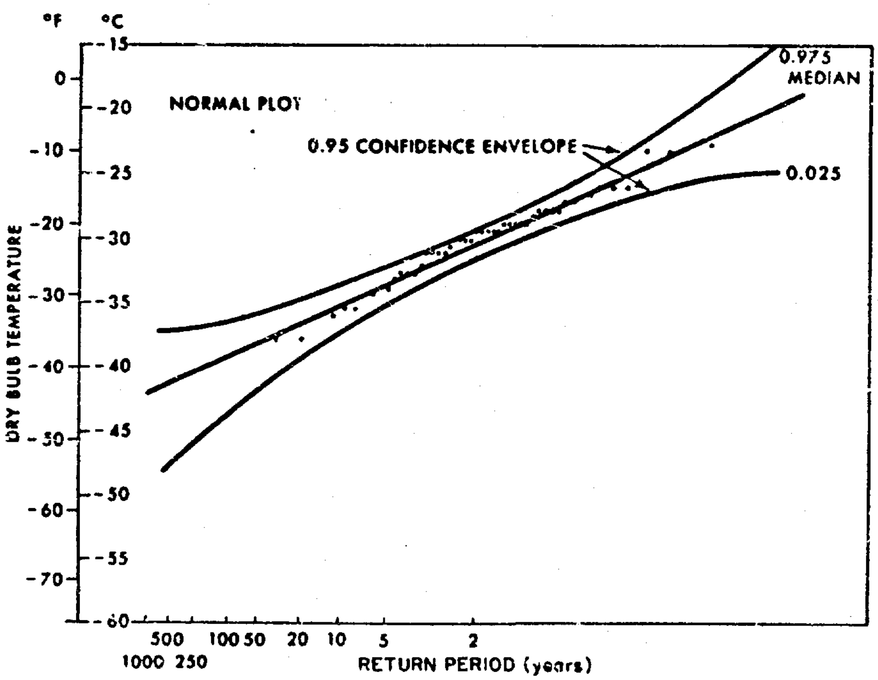

Figure 24. Naval Surface Environment, Expected Annual Minimum Temperature

1.1.2.2 Operations

Crutcher et al[7] present extreme minimum maritime temperatures for three locations: (1) ports which are open to sea traffic all months of the year; (2) ports which are closed to normal sea traffic by ice during part of the year; and (3) the open ocean. Closed ports have lower temperature minima than open ports, and open ports have lower minima than the open ocean. Since the extreme low temperatures experienced by closed ports tend to occur during the time of year that they are closed to shipping, it is logical that minima from open ports be used to represent low temperature extremes likely to be encountered by equipment designed for operation in or withstanding the maritime environment. Accordingly, only these minima are presented in this document and are recommended for MIL-STD-210B.

Based on a study of a number of open ports from around the world, Anchorage, Alaska, was chosen to represent the world's coldest open port. Hourly temperature records for Anchorage and nearby Elmendorf Air Force Base were combined to make a continuous record extending from 1952 to 1968. The coldest month and the month before and after were used. This record was inventoried and missing observations were obtained from the WBAN-10 forms and inserted in the record.

(Rather than directly compute temperature minima surpassed in 1, 5, 10, and 20 percent of the observations, Crutcher et al[7] proceeded directly to compute durations of low temperatures. It is possible, however, to estimate the 1, 5, 10, and 20% low temperature extremes by selecting from the 1, 5, 10, and 20% duration curves to be discussed below, those temperatures that "lasted" for only 1 hr.

A program was prepared to look at the data record and count the number of hours that a temperature remains at or below a given value. A listing was produced which presented a count of occurrences of each temperature for each duration interval from 1 hr consecutively out to 144 hr. From this list it was possible to calculate those temperature minima equalled or exceeded in 1, 5, 10, and 20 percent of the observations for each duration interval. These values are shown in Table 27. From this table we see that estimates of the 1, 5, 10, and 20 percent operational low temperature extremes are:

Percent Extreme	Temperature (°F)
1	-29.7
5	-18.7
10	-13.7
20	-7.3

Table 27. Low Temperature for Naval Surface Operations With 1, 5, 10, and 20 Percent Probabilities (Estimated at Duration Equal to 1 Hr), and Durations of Associated Temperatures

Probability		DURATION (hours) 1	2	3	4	5	6	7	8	9	10	11	12	18	24	36	48	72	96	120
1%	°F	-29.7	-29.2	-28.7	-28.2	-27.6	-27.2	-26.7	-26.2	-25.8	-25.3	-24.8	-24.2	-21.1	-18.5	-14.8	-17.4	-9.7	-8.6	-7.[illegible]
	°C	-34.2	-34.0	-33.7	-33.4	-33.1	-32.9	-32.6	-32.3	-32.1	-31.8	-31.6	-31.2	-29.6	-28.1	-26.0	-24.7	-23.2	-22.6	-21.8
5%	°F	-18.7	-18.2	-17.6	-17.2	-15.7	-16.2	-15.8	-15.3	-14.9	-14.6	-14.3	-13.4	-11.9	-10.1	-7.3	-4.9	-2.2	-0.8	+0.9
	°C	-28.2	-27.9	-27.6	-27.3	-27.1	-26.8	-26.6	-26.3	-26.1	-25.9	-25.7	-25.4	-24.4	-23.4	-22.8	-20.5	-19.0	-18.2	-17.2
10%	°F	-13.7	-13.3	-12.8	-12.4	-11.9	-11.6	-11.1	-10.7	-10.3	-9.9	-9.4	-9.1	-6.7	-5.6	-2.7	-1.1	+1.9	+2.5	+4.9
	°C	-25.4	-25.2	-24.9	-24.7	-24.4	-24.2	-23.9	-23.7	-23.5	-23.3	-23.0	-22.8	-21.5	-20.6	-19.3	-18.[illegible]	[illegible]	-[illegible].4	-15.1
20%	°F	-7.3	-7.0	-6.7	-6.4	-6.1	-5.8	-5.5	-5.2	-5.0	-4.7	-4.4	-4.1	-2.4	-0.9	+1.4	+2.5	+[illegible]	[illegible].8	+9.3
	°C	-21.8	-21.7	-21.5	-21.3	-21.2	-21.0	-20.8	-20.7	-20.6	-20.4	-20.2	-20.1	-19.1	-18.3	-17.8	16.3		14.0	-12.6

1.1.2.3 Withstanding

Along the lines discussed above in Section 1.1.2.2, Crutcher et al[7] also studied withstanding cold temperature extremes for the three maritime locations and, for the same reasons given above, only withstanding extremes from open ports will be presented in this document.

Again, the port used was Anchorage, Alaska. Using the minimum temperature in each year of record available from Anchorage and following the procedure outlined in Withstanding Section 1.1.1.3, Figure 24 was derived. For EDE's of 2, 5, 10, and 25 years, the low temperature 10 percent withstanding extremes from Figure 24 are:

EDE (Years)	Temperature (°F)
2	-34.1
5	-36.9
10	-38.7
25	-40.9

Crutcher et al[7] did not provide durations associated with the withstanding extremes. As a first approximation, the durations associated with the 1 percent operational extreme, Table 27, adjusted downward at each hourly interval for the difference between the 1 percent operational extreme and the 10 percent withstanding extremes, is recommended. That is, the following should be subtracted from the temperatures given in Table 27 to provide the durations associated with the withstanding extremes:

EDE (Years)	Temperature Increment (°F)
2	4
5	7
10	9
25	11

1.2 Humidity

See Section II.2. for a general discussion of water vapor content.

1.2.1 ABSOLUTE HUMIDITY

Readers interested in a general discussion of absolute humidity and its effect on equipment should read Section II.2.1.

1.2.1.1 High Absolute Humidity

Crutcher et al[7] did not present extremes of absolute humidity. However, the highest free-air absolute humidities possible occur over or adjacent to the warmest ocean waters. Studies[24] have shown these to be the Persian Gulf and adjacent

coastal waters. These are the same extremes that were presented in Chapter II, Section 2. 1. 1. 2 for ground operations. Therefore the values in this section should be used for the high absolute humidity operational extreme for the ocean and coastal ports.

1. 2. 1. 1. 1 HIGHEST RECORDED

See Section II. 2. 1. 1. 1.

1. 2. 1. 1. 2 OPERATIONS

See Section II. 2. 1. 1. 2.

1. 2. 1. 1. 3 WITHSTANDING

For withstanding high absolute humidity, the extremes given in Chapter II, Section 2. 1. 1. 3 for Belize, British Honduras, a seaport, should be used for reasons given in that section.

1. 2. 1. 2 Low Absolute Humidity

Crutcher et al[7] did not present extremes of low absolute humidity. Such extremes would be associated with extremes of low temperature. For design criteria, an absolute humidity given by assuming a 90 percent relative humidity with the low temperature extremes of Section 1. 1. 2 is recommended.

1. 2. 1. 2. 1 LOWEST RECORDED

The absolute humidity is associated with a 90 percent relative humidity at the temperature given in Section 1. 1. 2. 1.

1. 2. 1. 2. 2 OPERATIONS

The absolute humidities are associated with a 90 percent relative humidity at temperatures given in Section 1. 1. 2. 2.

1. 2. 1. 2. 3 WITHSTANDING

The absolute humidities are associated with a 90 percent relative humidity at the temperatures given in Section 1. 1. 2. 3.

1. 2. 2 RELATIVE HUMIDITY

Readers interested in a general discussion of relative humidity and its effect on equipment should read Section II. 2. 2.

1. 2. 2. 1 High Relative Humidity

Areas of high relative humidity can occur both in cold and warm climates. For a given value of relative humidity, more moisture is present at a high temperature than at a cold temperature. For this reason, only warm areas of high relative humidity (RH) were investigated by Crutcher et al.[7]

1.2.2.1.1 WITH HIGH TEMPERATURE

1.2.2.1.1.1 Highest Recorded

Relative humidities of 100 percent with warm temperatures have been observed in the maritime environment especially near the ocean surface. For an associated temperature, assume 93°F. This, the highest dew point recorded (given in Section II.2.1.1.1), occurred in a coastal port and most probably represented the air temperature near the ocean surface.

1.2.2.1.1.2 Operations

Crutcher et al[7] present extremes of high relative humidity for both port and open ocean locations. From their presentation, one can see that the relative humidity environment with accompanying warm temperature over the open ocean is more severe than in ports. Thus only that portion of their study will be presented.

Crutcher et al[7] studied climatic charts for areas of small wet bulb depression to find a warm area of high relative humidity on the open ocean. An observation count of data available from several Marsden Squares in the selected warm area of high relative humidity was prepared. Based on this count, Marsden Square 322 (Figure 21), located between 0° and 10°S and 130° and 140°E, was chosen as the most extreme area. The 1, 5, 10, and 20 percent high relative humidity extremes with warm temperatures for this location in the most extreme month were determined from an ordered listing of the data. These are:

Percent Extreme	Percent Relative Humidity
1	100
5	96
10	91
20	84

To provide a typical diurnal cycle associated with the 1 percent extreme high relative humidity, hourly values of relative humidity on the dates in the data record when the 1 percent value, 100 percent, was equalled, were determined and averaged by hour. In addition to the relative humidity, average hourly values of concurrent parameters—temperature and insolation—were also determined. This information is graphically portrayed in Figure 25. The 1 percent high relative humidity extreme, 100 percent, occurs from near midnight to 0500 LST and the minimum relative humidity reached, still over 90 percent, occurs at about 1430 LST. The maximum temperature accompanying these humidities is about 84°F occurring near 1500 LST, and the minimum is 77°F occurring at 0200 LST; this gives a daily temperature range of only 7°F. Maximum solar insolation

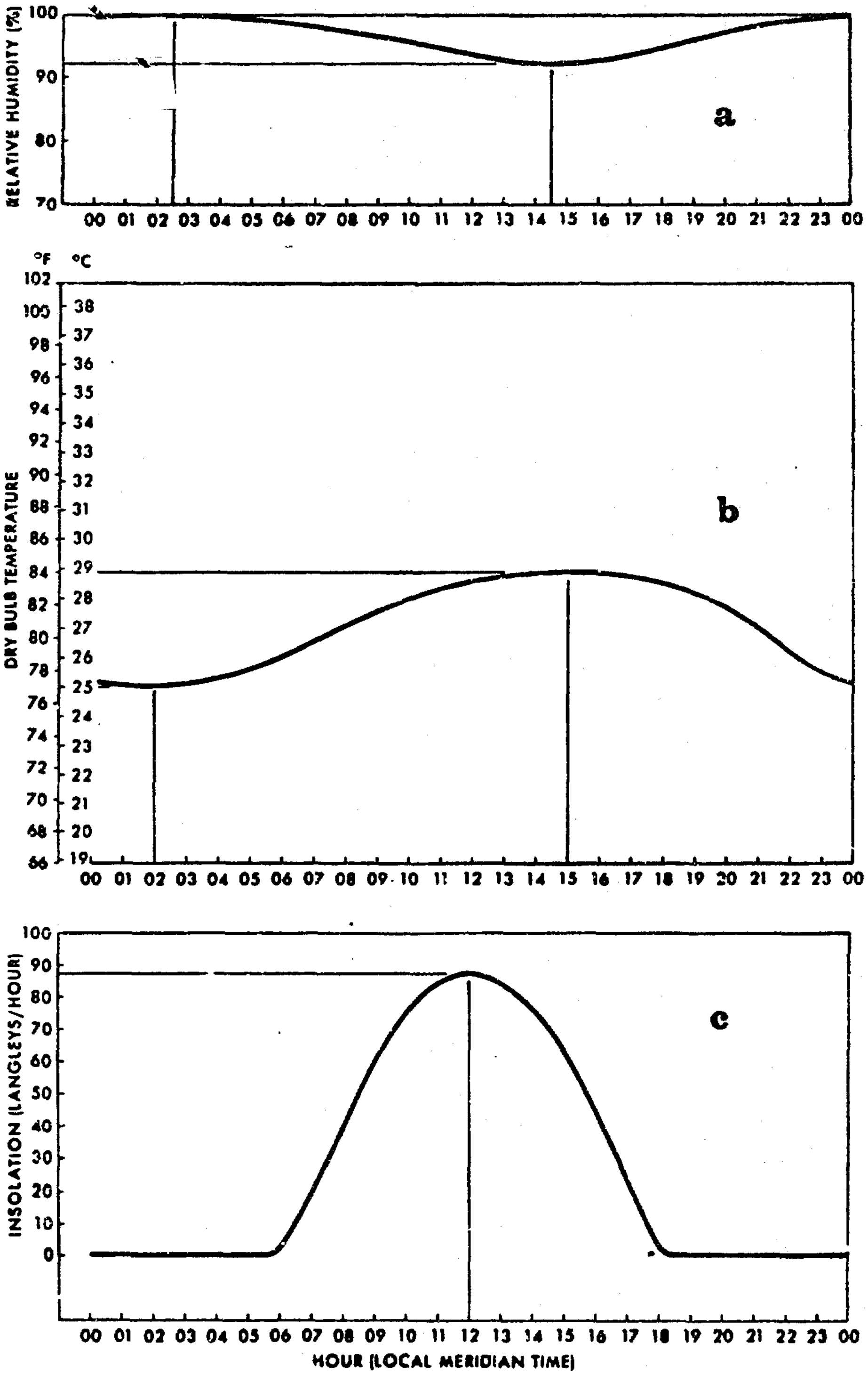

Figure 25. Diurnal Cycle of Average (a) Relative Humidity, (b) Temperature, and (c) Insolation, Associated With the 1 Percent High Relative Humidity (With High Temperatures) Extreme for the Naval Surface Environment

occurs at 1200 LST and is equal to about 88 langleys/hr (324 BTU/ft^{2}hr). This information, along with analogous cycles for 5, 10, and 20 percent extremes, is presented in tabular format in Table 28. (The extreme relative humidities in the table and figure are average values based on all days on which the 1, 5, 10, and 20 percent extremes of humidity were equalled or exceeded; these relative humidities therefore may be slightly higher than the previously quoted 1, 5, 10, and 20 percent extremes.)

1.2.2.1.1.3 Withstanding

Not available.

1.2.2.1.2 WITH LOW TEMPERATURE

Relative humidities of 100 percent are common with low temperatures. Accordingly relative humidities of 100 percent with the low temperature extremes of Section 1.1.2 are recommended for the high relative humidity with low temperature extremes.

1.2.2.1.2.1 Highest Recorded

Relative humidity of 100 percent with the low temperature extreme in Section 1.1.2.1.

1.2.2.1.2.2 Operations

Relative humidity of 100 percent with the low temperature extremes in Section 1.1.2.2.

1.2.2.1.2.3 Withstanding

Relative humidity of 100 percent with the low temperature extremes in Section 1.1.2.3.

1.2.2.2 LOW RELATIVE HUMIDITY

Crutcher et al[7] indicated that for low relative humidity environments, low relative humidity in conjunction with high temperature is more significant because of drying considerations than low relative humidity with low temperature. They therefore only investigated that combination of elements.

1.2.2.2.1 With High Temperature

1.2.2.2.1.1 LOWEST RECORDED

Crutcher et al[7] do not directly report on lowest relative humidities ever observed with high temperatures. However, in ports located near deserts, when there is strong circulation from the land the RH will be a few percent.

Table 28. Diurnal Cycles of Average Relative Humidity, Temperature, and Solar Insolation Associated With Extremes of High Relative Humidity (With High Temperatures) in the Naval Surface Environment

(a) 1% Extreme

ELEMENT	00	01	02	03	04	05	06	07	08	09	10	11	12	13	14	15	16	17	18	19	20	21	22	23	00
RELATIVE HUMIDITY %	99.5	99.8	100	100	[illegible]	[illegible]	98.8	98.2	97.5	96.6	95.7	94.7	93.7	92.9	92.5	92.5	93.0	93.7	94.8	96.1	97.3	98.2	98.9	99.3	99.5
AIR TEMPERATURE °F	77.4	77.2	77.1	77.3	77.6	78.1	[illegible]	79.8	80.8	81.7	82.4	83.0	83.5	83.8	84.0	84.1	84.0	83.6	83.3	82.8	81.9	80.6	79.2	77.9	77.6
°C	25.2	25.1	25.1	25.2	25.3	25.6	26.0	26.6	27.1	27.6	28.0	28.3	28.6	28.8	28.9	28.9	28.9	[illegible]	28.5	28.2	27.7	27.0	26.2	25.5	25.2
INSOLATION LY/HR	00	00	00	00	00	00	03	[illegible]	39	50	74	83	87	83	76	63	44	23	03	00	00	00	00	00	00

(b) 5% Extreme

ELEMENT	00	01	02	03	04	05	06	07	08	09	10	11	12	13	14	15	16	17	18	19	20	21	22	23	00
RELATIVE HUMIDITY %	97.5	97.5	97.5	[illegible]	97.4	96.6	96.0	95.4	94.6	93.5	92.5	91.2	90.0	88.2	86.4	86.0	88.6	89.9	91.3	92.8	94.3	95.4	96.3	97.0	97.5
AIR TEMPERATURE °F	77.2	77.0	76.9	77.0	77.4	77.9	78.6	79.4	80.2	81.2	82.0	82.6	83.1	83.4	83.6	83.6	83.5	83.2	82.8	82.1	81.3	80.2	78.9	77.8	77.2
°C	25.1	25.0	24.9	25.0	25.2	25.5	25.8	26.3	26.8	[illegible]	27.8	28.1	28.4	28.6	28.7	28.7	28.6	28.4	28.2	27.8	27.4	26.8	26.1	25.4	25.1
INSOLATION LY/HR	00	00	00	00	00	00	03	19	39	50	74	83	87	83	76	63	44	23	03	00	00	00	00	00	00

(c) 10% Extreme

ELEMENT	00	01	02	03	04	05	06	07	08	09	10	11	12	13	14	15	16	17	18	19	20	21	22	23	00
RELATIVE HUMIDITY %	93.5	93.5	93.5	93.6	93.5	93.5	93.4	93.1	92.7	91.6	91.6	[illegible]	89.0	88.0	87.0	86.4	86.2	86.7	87.9	89.5	90.8	91.7	92.5	93.2	93.5
AIR TEMPERATURE °F	77.2	76.9	76.6	76.8	77.1	77.6	78.2	79.0	79.8	80.8	81.5	82.1	82.4	82.7	82.9	82.9	82.8	82.6	82.2	81.6	80.7	79.7	78.5	77.6	77.2
°C	25.1	24.9	24.8	24.9	25.1	25.3	25.7	26.1	26.6	27.1	27.5	27.8	28.0	28.2	28.3	28.3	28.2	28.1	27.9	27.6	27.1	26.5	25.8	25.3	25.1
INSOLATION LY/HR	00	00	00	00	00	00	03	19	39	50	74	83	87	83	76	63	44	23	03	00	00	00	00	00	00

(d) 20% Extreme

ELEMENT	00	01	02	03	04	05	06	07	08	09	10	11	12	13	14	15	16	17	18	19	20	21	22	23	00
RELATIVE HUMIDITY %	88.4	88.6	88.8	88.9	88.9	[illegible]	89.1	88.9	88.6	87.6	86.9	85.9	85.0	84.2	83.4	82.2	81.3	81.4	82.6	84.4	85.7	86.8	87.7	88.2	88.4
AIR TEMPERATURE °F	76.9	76.6	76.5	76.4	76.9	77.4	78.0	78.8	79.5	80.4	81.1	81.7	82.1	82.3	82.4	82.5	82.4	82.1	81.7	81.2	80.4	79.3	78.0	77.3	76.9
°C	24.9	24.8	24.7	24.7	24.9	25.2	25.6	26.0	26.4	26.9	27.3	27.6	27.8	27.9	28.0	28.1	28.0	27.8	27.6	27.3	26.9	26.3	25.6	25.2	24.9
INSOLATION LY/HR	00	00	00	00	00	00	03	19	38	50	74	83	87	83	76	63	44	23	03	00	00	00	00	00	00

1.2.2.2.1.2 OPERATIONS

Crutcher et al[7] present extremes of low relative humidity for both port and open ocean locations. Of these two maritime environments, ports have the most extreme low relative humidity/high temperature regimes. Therefore, only that portion of their study will be presented.

The location and data availability on Abadan made this station a first choice for a port of low relative humidity. A check was made of several southwest U.S. port locations and none were found to be as dry as Abadan. Hourly observations of relative humidity from Abadan were listed in an ordered fashion, and the month which had the lowest 1 percent low relative humidity extreme was selected to be representative of the worst month. Also, from the ordered listing of the relative humidity for this month, low humidities equalled or surpassed in 5, 10, and 20 percent of the observations were determined. These 1, 5, 10, and 20 percent low relative humidity extremes are:

Percent Extreme	Percent Relative Humidity
1	12
5	15
10	17
20	21

To provide a typical diurnal cycle associated with the 1 percent probable low relative humidity of 12 percent, hourly values of relative humidity on the dates in the Abadan data record when relative humidities were 12 percent or lower were determined and averaged by hour. Average hourly values of temperature and insolation were also determined for these dates. Figure 26 shows this information. The extreme low relative humidity of 12 percent occurs at 1500 LST and is associated with a temperature of about 113°F. The maximum relative humidity during extremely dry days is about 51 percent and occurs at 0630 LST; at this time the temperature is 79°F. Insolation has a peak value of 95 langleys/hr (350 BTU/ ft^2/hr) occurring at local noon. Tabulations of the daily cycle with these values along with cycles for 5, 10, and 20 percent low humidity extremes are presented in Table 29. (The low relative humidities in the table and in the figure are average values based on all days on which the 1, 5, 10, and 20 percent low humidity extremes were equalled or lower; these relative humidities may therefore be slightly lower than the previously quoted 1, 5, 10, and 20 percent extremes.)

1.2.2.2.1.3 Withstanding

Not available.

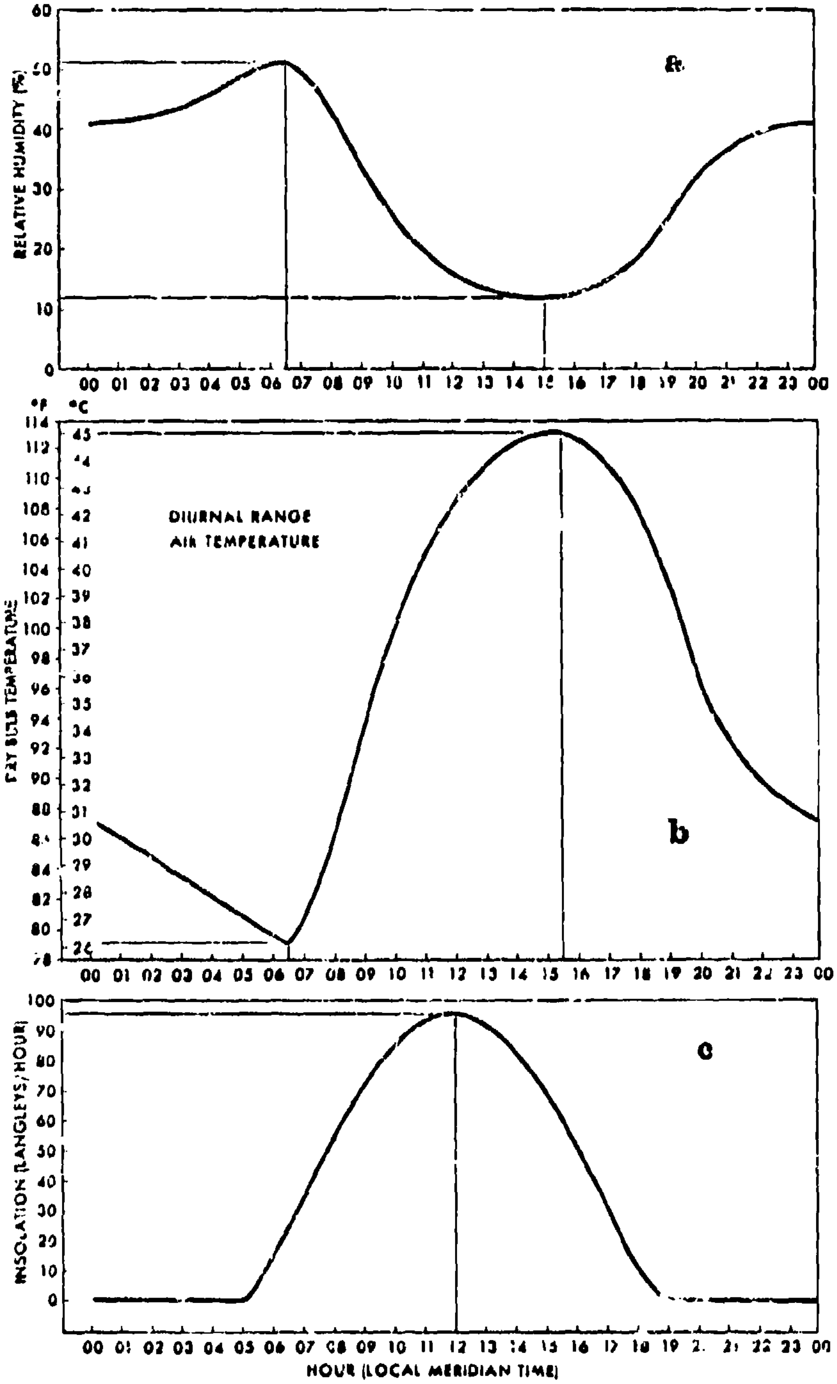

Figure 26. Diurnal Cycle of Average (a) Relative Humidity, (b) Temperature, and (c) Insolation Associated With the 1 Percent Low Relative Humidity (With Warm Temperatures) Extreme for the Naval Surface Environment

Table 29. Diurnal Cycles of Average Relative Humidity, Temperature, and Solar Insolation Associated With Extremes of Low Relative Humidity (With Warm Temperatures) in the Naval Surface Environment

(a) 1% Extreme

ELEMENT	00	01	02	03	04	05	06	07	08	09	10	11	12	13	14	15	16	17	18	19	20	21	22	23	00
RELATIVE HUMIDITY %	41.0	41.5	42.2	43.5	45.8	48.6	50.9	49.5	43.0	33.8	25.6	19.8	15.9	13.6	12.3	11.9	12.6	14.4	18.0	24.3	31.4	36.2	39.0	40.7	41.0
AIR TEMPERATURE °F	87.4	86.1	84.8	83.6	82.2	80.9	79.5	80.9	86.3	93.6	100.1	105.0	108.6	111.0	112.5	113.2	112.7	111.0	108.1	[illegible]	97.0	92.8	90.1	88.4	87.4
°C	30.8	30.1	29.3	28.7	27.9	27.2	26.4	27.2	30.2	34.2	37.8	40.6	42.6	43.9	44.7	45.1	44.8	43.9	42.3	39.6	36.1	33.8	32.3	31.3	30.8
INSOLATION LY/HR	00	00	00	00	00	00	15	34	55	72	85	93	96	62	83	70	50	31	11	00	00	00	00	00	00

(b) 5% Extreme

ELEMENT	00	01	02	03	04	05	06	07	08	09	10	11	12	13	14	15	16	17	18	19	20	21	22	23	00
RELATIVE HUMIDITY %	41.6	42.0	44.0	45.9	47.8	50.0	51.0	49.8	43.6	35.0	27.2	26.2	17.4	15.1	14.3	13.5	14.3	15.8	18.9	25.3	32.0	36.8	39.7	41.1	41.6
AIR TEMPERATURE °F	87.8	86.6	85.1	83.8	82.5	81.2	80.2	81.9	87.3	93.6	99.7	104.6	108.4	110.8	112.1	112.7	112.5	111.2	108.3	103.6	97.9	93.3	90.6	89.1	87.8
°C	31.0	30.3	29.5	28.8	28.1	27.3	26.8	27.7	30.7	34.2	37.6	40.3	42.4	43.8	44.5	44.8	44.7	44.0	42.4	39.8	36.6	34.1	32.6	31.7	31.0
INSOLATION LY/HR	00	00	00	00	00	00	15	34	55	72	85	93	96	92	83	70	50	31	11	00	00	00	00	00	00

(c) 10% Extreme

ELEMENT	00	01	02	03	04	05	06	07	08	09	10	11	12	13	14	15	16	17	18	19	20	21	22	23	00
RELATIVE HUMIDITY %	42.7	44.0	45.3	46.7	48.5	50.2	51.3	49.6	43.9	36.2	28.6	22.7	18.3	16.7	15.8	15.3	15.7	17.0	20.0	26.5	34.5	38.2	40.5	42.1	42.7
AIR TEMPERATURE °F	88.4	87.0	85.6	84.4	83.3	82.2	81.3	82.7	88.3	94.2	100.2	105.3	108.9	111.1	112.2	112.5	112.3	111.1	108.6	103.5	97.5	93.7	91.1	89.6	88.4
°C	31.3	30.6	29.8	29.1	28.5	27.9	27.4	28.2	31.3	34.6	37.9	40.7	42.7	43.9	44.6	44.8	44.6	43.9	42.6	39.7	36.4	34.3	32.8	32.0	31.3
INSOLATION LY/HR	00	00	00	00	00	00	15	34	55	72	85	93	96	92	83	70	50	31	11	00	00	00	00	00	00

(d) 20% Extreme

ELEMENT	00	01	02	03	04	05	06	07	08	09	10	11	12	13	14	15	16	17	18	19	20	21	22	23	00
RELATIVE HUMIDITY %	44.8	46.0	47.1	48.2	49.6	51.9	54.2	51.8	45.1	37.7	30.0	25.0	21.7	19.3	17.8	17.1	17.5	19.3	23.0	30.0	[illegible]	[illegible]	42.8	43.2	44.8
AIR TEMPERATURE °F	89.1	87.7	86.3	85.0	83.9	83.0	82.1	83.9	89.2	95.0	101.0	105.2	108.4	110.7	111.7	112.1	111.8	110.6	107.4	102.8	97.2	94.1	91.9	90.3	89.1
°C	31.7	30.9	30.2	29.4	28.8	28.3	27.8	28.8	31.8	35.0	38.3	40.7	42.4	43.7	44.3	44.5	44.3	43.7	42.2	39.3	36.2	34.5	33.3	32.4	31.7
INSOLATION LY/HR	00	00	00	00	00	00	15	34	55	72	85	93	96	92	83	70	50	31	11	00	00	00	00	00	00

1.2.2.2.2 WITH LOW TEMPERATURE

1.2.2.2.2.1 Lowest Recorded

Not available.

1.2.2.2.2.2 Operations

Not available.

1.2.2.2.2.3 Withstanding

Not available.

1.3 Wind Speed

See Section II. 3. for a general discussion of wind and its characteristics.

1.3.1 HIGHEST RECORDED

Crutcher et al[7] do not list the highest wind speed ever recorded in the maritime environment. Strongest maritime winds, except for winds in tornados/waterspouts, are associated with tropical storms (especially typhoons) over the open ocean. Such wind speed extremes are given in Section II. 3. 1.

1.3.2 OPERATIONS

Wind speeds equalled or exceeded in 1, 5, 10, and 20 percent of the hourly observations from the windiest location in maritime areas (be it port or open ocean) during the windiest month have not been determined. Crutcher et al[7] present percent frequency occurrences of wind speed in different wind speed categories for Adak, Alaska, the windiest port (it is not indicated whether these statistics are based on all data available or on data for only the windiest month).

For over the ocean, they present the percentage frequency of occurrences of wind speed (1-min average) equal to or greater than 34 knots at Ocean Station Vessel, OSV, Bravo (56.5°N, 51.0°W).

They also present durations of wind speeds by similar wind speed categories for different probability levels. These statistics show, as expected, that winds are stronger and high winds more frequent over the ocean than in ports; 22.3 percent of wind speed occurrences at OSV Bravo were equal to greater than 34 knots versus 6.0 percent for Adak, and 1 percent of such occurrences lasted 48 hr versus 18.4 hr for Adak.

For designing equipment for the naval surface environment, it is recommended that the 1, 5, 10, and 20 percent winds presented in Chapter II, Section 3, be used as an interim measure until such statistics are prepared for the naval

surface environment. Wind speeds presented in this section are representative of a coastal location; if used for design in the marine environment they should be employed with the realization that since high winds tend to last longer over the open ocean, extreme winds will be greater than over land.

1.3.3 WITHSTANDING

Crutcher et al[7] studied annual wind speed extremes at port and open ocean locations, and also in typhoons. Peak gust data were used for ports and the open ocean and maximum reported winds for typhoons. This study showed Adak, Alaska to be the port with the highest winds. Ocean Station Delta (near 44°N, 41°W) was the windiest open ocean area and it had higher wind extremes than Adak. Both of these maritime locations had much lower annual wind extremes, however, than those found in typhoons. Accordingly, only results from that portion of their study will be presented here.

Data on typhoons for the years 1945-1967 were examined for maximum wind speed. For the years 1945-1952 only data for the period from September to December were readily available; the use of this data requires the reasonable assumption that typhoons have their strongest winds during this time of the year.

Using the strongest wind in each year and following the procedure outlined in Withstanding Section 1.1.1.3, Figure 27 was derived. As explained and

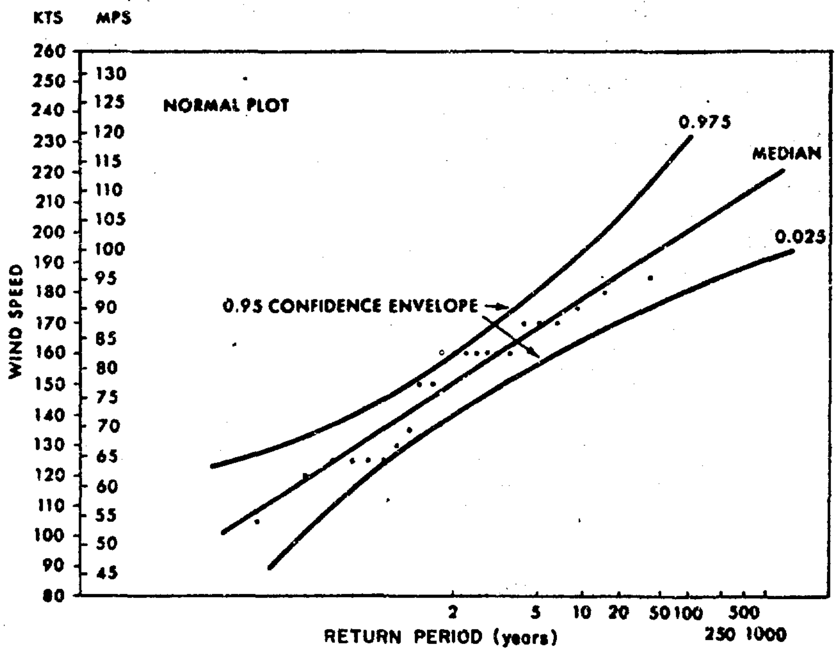

Figure 27. Probable Naval Surface Environment, Annual Maximum Wind Within Entire Tropical Storm Area

exemplified in Section I.2.4, it is possible, using information presented in such a figure, to determine design withstanding extremes for equipment of various EDE's and for various percent risks. For the 10 percent extreme, and for EDE's of 2, 5, 10, and 25 years, the following extremes are obtained:

EDE (Years)	Wind Speeds (Knots)
2	186
5	194
10	200
25	208

These values are considerably higher than wind withstanding extremes presented in the Ground Section II.3. which are also based on typhoon winds. This is because the extremes listed above are based on all typhoons in given years regardless of location rather than typhoons affecting a specific location. Since a given ship can only be in one location at a time, these extremes in effect represent a far less than 10 percent risk. Therefore it is recommended that withstanding extremes presented in Chapter II, Section 3, be used for the maritime environment.

1.4 Precipitation

1.4.1 RAINFALL RATE

Crutcher et al[7] indicate that since quantitative rainfall rates are not directly observed in the marine environment, a meaningful study of this element would be very difficult to accomplish. Because of this, and since the rainfall rate over continents can be considered to be representative of the worst to be expected at coastal or open ocean locations, they recommend that the land study will be sufficient for this element. (See Section II.4.)

1.4.1.1 Highest Recorded

See Sections II.4.1.1 and II.4.1.3.

1.4.1.2 Operations

See Sections II.4.1.2 and II.4.1.3.

1.4.1.3 Withstanding

See Section II.4.1.4.

1.4.2 SNOW

Crutcher et al[7] did not provide snow extremes.

1.4.2.1 Blowing Snow

1.4.2.1.1 HIGHEST RECORDED

Not available.

1.4.2.1.2 OPERATIONS

Not available.

1.4.2.1.3 WITHSTANDING

Concept not applicable to this climatic element.

1.4.2.2 Snowload

Snowload is not a general problem in the design of maritime equipment. If, however, items need to be designed for snowload, the results in Ground Section II.4.2.2.3.2 for temporary equipment, 20 lb/ft^2 based on snowfalls from a single storm, are probably most applicable to the maritime situation.

1.4.2.2.1 HIGHEST RECORDED

See Section II.4.2.2.1.2.

1.4.2.2.2 OPERATIONS

Concept not applicable to this climatic element.

1.4.2.2.3 WITHSTANDING

See Section II.4.2.2.3.2.

1.4.3 ICE ACCRETION

Crutcher et al[7] did not present extremes of ice accretion. However, in a later correspondence,[62] Crutcher did provide information which permitted the recommendation of ice accretion extremes. This information is basically design criteria in use by Iceland, the United Kingdom, and the USSR.

1.4.3.1 Highest Recorded

Crutcher[62] reports on ice 17 cm thick measured on a Russian vessel. This corresponds to a load of 143 kg/m^2 for a typical ice density of 847 kg/m^3.

1.4.3.2 Operations

Not available.

1.4.3.3 Withstanding

Based on USSR and UK design criteria reported by Crutcher,[62] the following limits are recommended. For exposed horizontal surfaces, a loading of 30 kg/m^2; this corresponds to an ice thickness of 3.5 cm with a typical density of 847 kg/m^3. For exposed vertical surfaces, a loading of 15 kg/m^2, corresponding to a thickness of 1.8 cm.

1.4.4 HAIL SIZE

Section II.4.4 shows that hail occurs so infrequently over land that it need not be considered unless hail-caused failure would endanger life. Hail is even rarer for the naval surface environment and therefore no hail extremes are given. The values in Section II.4.4 should be considered when failure of naval equipment due to hail would endanger life.

1.4.4.1 Largest Recorded

See note above.

1.4.4.2 Operations

See note above.

1.4.4.3 Withstanding

Not available.

1.5 Pressure

1.5.1 HIGH PRESSURE

1.5.1.1 Highest Recorded

Not computed.

1.5.1.2 Operations

Not computed.

1.5.1.3 Withstanding

Not computed.

1.5.2 LOW PRESSURE

1.5.2.1 Lowest Recorded

See Section II.5.2.1 which lists and discusses the lowest recorded sea-level pressure, – 877 mb.

1.5.2.2 Operations

A determination of the 1 percent operational sea-level low pressure extreme (the sea-level low pressure that is equalled or exceeded during 99 percent of the time (hours) in maritime areas having the lowest pressures during the time of year when low pressures are most common) has not been made since it is presumed that designing for the low pressure record extreme of 877 mb, presented in Section 1.5.2.1, is neither an economic nor a technological problem.

1.5.2.3 Withstanding

A determination of the 10 percent withstanding low pressure extreme (that value of pressure that has a 10 percent probability of occurring or being exceeded during various EDE's (years) of equipment in an extreme area and season) has not been made for reasons given in Section 1.5.2.2.

1.6 Density

See Section II.6. for a discussion of density extremes.

1.6.1 HIGH DENSITY

See Section II.6.1 for a discussion of high density extremes.

1.6.1.1 Highest Recorded

Taking the lowest recorded air temperature of -37°F and assuming that it was accompanied by a pressure of 1050 mb, a density of 1.556 kg/m^3 is obtained. This can be assumed to approximate the highest likely to be recorded.

1.6.1.2 Operations

Taking the 1 percent low temperature extreme of -29.7°F with an assumed pressure of 1050 mb yields a density of 1.530 kg/m^3. This is a likely 1 percent high density extreme.

1.6.1.3 Withstanding

The withstanding concept is not applicable to density.

1.6.2 LOW DENSITY

Extremes of low density in the maritime environment will occur where temperatures are highest and pressures lowest. Using the extreme of high temperature (123°F) with an assumed pressure of 1000 mb results in a density of 1.075 kg/m^3. Using the extreme of low pressure (877 mb) with an assumed temperature of 85°F results in a density of 1.011 kg/m^3. Thus the lowest recorded density in the maritime environment is associated with the low pressure extreme. However, since such low pressures are rare occurrences, the 1 percent low density extreme required for operations should be based on the 1 percent high temperature.

1.6.2.1 Lowest Recorded

As described above, a density of 1.011 kg/m^3 can be assumed for lowest recorded.

1.6.2.2 Operations

The 1 percent high temperature extreme with which to calculate the 1 percent low density extreme is 118°F. Assuming a pressure of 1000 mb with this temperature results in a density of 1.085 kg/m^3.

1.6.2.3 Withstanding

The withstanding concept is not applicable to density.

1.7 Ozone Concentration

Crutcher et al[7] did not present extremes of ozone concentration for the naval surface environment. Extremes given in Section II.7. are recommended until criteria for the naval surface environment are determined.

1.7.1 HIGHEST RECORDED

See Section II.7.1.

1.7.2 OPERATIONS

See Section II.7.2.

1.7.3 WITHSTANDING

See Section II.7.3.

1.8 Sand and Dust

A study of these extremes for the maritime environment has not been made. Maritime extremes of these parameters would probably occur in port locations for which the extremes in Section II.8. are applicable and recommended.

1.8.1 HIGHEST RECORDED

Not available.

1.8.2 OPERATIONS

See Section II.8.5.2.

1.8.3 WITHSTANDING

Not available.

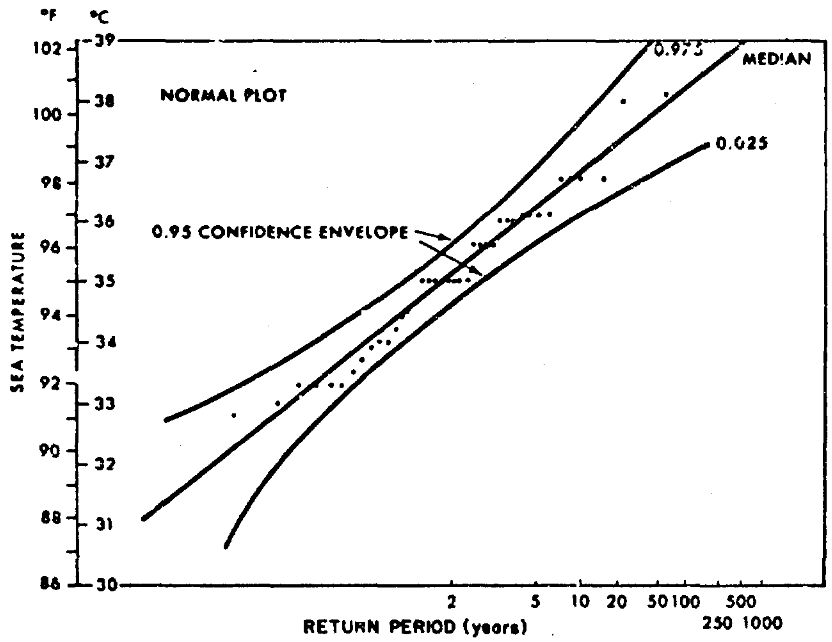

Figure 28. Probable Annual High Sea Surface High Temperature

1.9 Surface Water Temperature

1.9.1 SURFACE WATER HIGH TEMPERATURE

1.9.1.1 Highest Recorded

Crutcher et al[7] do not specifically point out the world's highest recorded surface water temperature, but from the plot of temperature points on Figure 28, it can be noted that a temperature of about 100.5°F has been observed in the Persian Gulf.

1.9.1.2 Operations

Because of the general unavailability of sea surface temperature data for ports, Crutcher et al[7] present information for the open ocean only. However, based on the few port sea surface temperatures at their disposal, they recommend that extremes of sea surface temperature determined over the open ocean would also be applicable to ports.

A survey was made of U.S. Navy marine atlases and Naval Oceanographic Office publications for areas of maximum sea surface temperature. The area of highest sea temperature was found in the Persian Gulf (Marsden Square 103, Figure 21). The sea surface temperature data from MS 103 for the warmest month, August, were listed in descending order and from the total observation count, the temperatures equalled or exceeded in 1, 5, 10, and 20 percent of the observations were determined. These percent extremes are:

Percent Extreme	Temperature (°F)
1	96.1
5	95.0
10	93.9
20	93.0

Diurnal cycles are also provided, but amplitudes are so small that a single value should suffice in any design problem.

1.9.1.3 WITHSTANDING

Annual extremes of sea surface temperature in the Persian Gulf were analyzed following the procedures outlined in WithstandingSection 1.1.1.3 and Figure 28 was devised. For the 10 percent extreme, and for planned EDE's of 2, 5, 10, and 25 years, the high sea surface temperature withstanding extremes are:

EDE (Years)	Temperature (°F)
2	99.1
5	100.0
10	100.8
25	101.5

1.9.2 LOW SURFACE WATER TEMPERATURE

1.9.2.1 Lowest Recorded

Crutcher et al[7] do not specifically point the the world's lowest recorded surface water temperature, but a review of the plot of temperature points in Figure 29 indicates a temperature of as low as 22°F has been observed (off the coast of Newfoundland, Canada).

1.9.2.2 Operations

Because of the general unavailability of sea surface temperature data for ports, Crutcher et al[7] present information for the open ocean only. However, low sea surface temperature extremes determined for the open ocean should not be substantially different from those in ports.

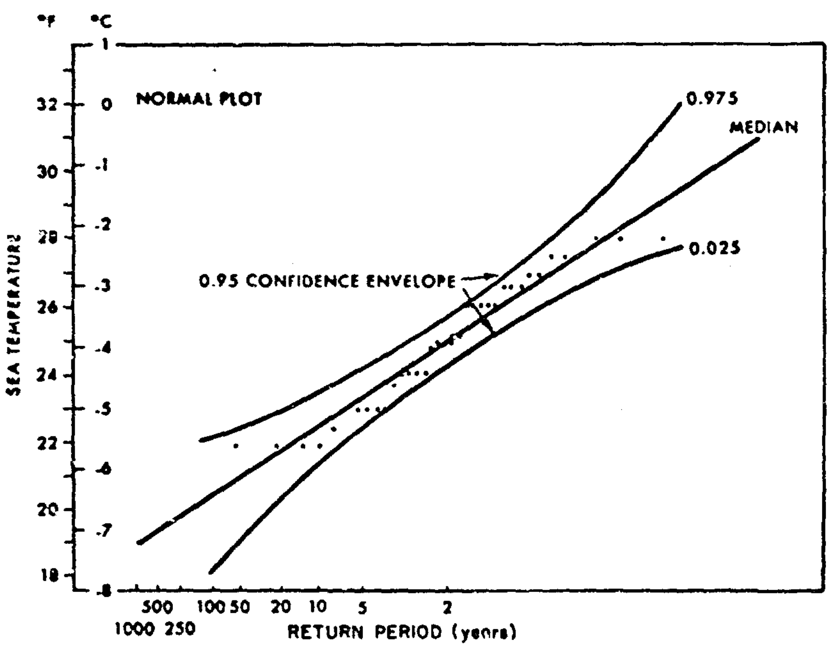

Figure 29. Probable Annual Low Sea Surface Temperature

Sea surface temperature records from OSV Bravo were analyzed and the 1, 5, 10, and 20 percent extremes determined from an ordered listing of the data. As the area with coldest water temperatures is south of the OSV Bravo position, the Bravo data were shifted about 4°F downward to be more compatible with the withstanding data to be presented in Section 1.9.2.3. The 1, 5, 10, and 20 percent low sea surface temperature extremes are:

Percent Probable Extreme	Temperature (°F)
1	28.2
5	29.4
10	30.5
20	31.4

1.9.2.3 Withstanding

U.S. Navy marine atlases were used to locate areas of minimum sea temperatures. An area of particularly cold sea temperatures was discovered off the coast of Newfoundland, Canada. The sea temperature observations for January, February, and March were listed in ascending order for the area off the coast of Newfoundland (MS 149 and 150, Figure 21). The data were analyzed in the same manner as outlined in Section 1.1.1.3 and are graphically presented in Figure 29. For the 10 percent extreme and for planned EDE's of 2, 5, 10, and 25 years, the low sea surface temperature withstanding extreme's are:

EDE (Years)	Temperature (°F)
2	21.7
5	21.0
10	20.5
25	19.8

1.10 Surface Water Salinity

The variability of salinity over the ocean has not been determined to the extent that statements can be made as to the distribution extremes. Salinities over the North Pacific and North Atlantic Oceans of greater than 36.0 parts per thousand ($^{o}/oo$) and 37.0 $^{o}/oo$, respectively have been measured. Average maximum salinities of about 41 $^{o}/oo$ in the northern parts of the Red and Arabian Seas are also indicated and extremes of 45 $^{o}/oo$ have been measured.

1.10.1 HIGHEST RECORDED

Not available.

1.10.2 OPERATIONS

Not available.

1.10.3 WITHSTANDING

Not available.

1.11 Wave Height and Spectra

Both the mean height of the highest waves and extreme wave heights are important in the design of ships. In addition, the response induced in ships by the frequencies and energies of the waves or wave trains is important. These factors are interrelated such that standardized design values of extremes cannot be specified. Designers should utilize Lewis[63] for information on wave height and spectra relevant to design.

2. NAVAL AIR ENVIRONMENT

Atmospheric extremes for worldwide air operations are found in Section IV. However, upper air extremes of high and low temperature and low absolute humidity in the naval air environment differ significantly from the corresponding extremes in Section IV at altitudes below about 52,000 ft (16 km). Equipment destined for use only in the naval air environment should be designed for values of extremes of these elements found in this section and values of extremes of the other elements in Section IV.

Crutcher et al[7] did not provide the extremes found in this section. They were furnished to AFCRL (LKI) at a later time in two separate correspondences;[64,65] the work was performed by personnel of the National Climatic Center, Asheville, N.C.

2.1 Temperature

Upper air environmental temperature extremes over navigable waters and ports are presented in this section. Low and high temperature extremes are given in heights above sea level and pressure altitudes up to 16 km. Above this level the atmospheric profiles are coincident with those given in Section IV. The profiles presented do not represent hydrostatically internal consistency of the atmosphere. They are simply envelopes of extreme conditions.

64. King, J.W. (1972) Temperature Extremes and Densities Aloft over Navigable Waters, enclosure to letter 3146 ser 76064/533 of 29 November 1972 from Officer-in-Charge NWSED, Asheville, N.C. to Mr. Norman Sissenwine, AFCRL (LKI).

65. King, J.W. (1973) High and Low Densities/Temperatures Extremes and at-Sea Temperature Extremes, enclosure to letter 3146 ser 76064/134 of 21 February 1973 from Officer-in-Charge, NWSED, Asheville, N.E. to Norman Sissenwine, AFCRL (LKI).

Data for extreme profiles for naval operations came primarily from Crutcher and Meserve[66] and Taljaard et al.[67] The profiles were developed from monthly mean values and standard deviations of atmospheric parameters at specified altitudes. Values for risk probabilities were determined by a statistical approach coupled with empirical data. It was attempted to make the extreme profiles realistic to naval operations.

Highest temperatures generally occur in the Northern Hemisphere summer. Up to about 12 km these high temperatures are found over the Arabian Sea. Above this level the extreme high temperatures are found near the Aleutian Islands. Lowest temperatures are found during winter. Up to about 8 km they occur over the North Atlantic Ocean off the coast of Labrador. Above 8 km, coldest temperatures are found over the waters circling Antarctica. It should be noted that the worldwide navigable waters stretched from 60°N to 60°S. It was felt that poleward of these boundaries naval air operations would essentially cease because of sea ice or other harsh environmental factors.

2.1.1 HIGH TEMPERATURE

2.1.1.1 Highest Recorded

The highest likely temperatures are given in Table 30 at heights above sea level and pressure altitudes. Likely densities accompany temperature extremes at heights above sea level; departures in these values of up to ±15 percent are possible.

2.1.1.2 Operations

One percent extreme temperatures are given in Table 31 at heights above sea level and at pressure altitudes. Likely densities accompany these temperature extremes at heights above sea level; departures in these values of up to ±15 percent are possible. The temperature value at 0 km in Table 31 is for operations in hot coastal ports. For equipment only required to operate at sea, the criteria at 0 km is 92°F (33°C).[65]

The 5, 10, and 20 percent high temperature extremes are given in Table 32. Accompanying densities for heights above sea level are given in Table 33. The temperature values at 0 km in Table 32 are for operations in hot coastal ports. For equipment only required to operate at sea, the criteria at 0 km are 88°F

66. Crutcher, H. L., and Meserve, J. M. (1970) Selected Level Heights, Temperatures and Dew Points for the Northern Hemisphere NAVAIR 50-K-52, Commander, US Naval Weather Service Command.

67. Taljaard, J. J., et al (1969) Climate of the Upper Air, Southern Hemisphere 1, NAVAIR 50-K-55, Commander, U.S. Naval Weather Service Command.

(31°C) for the 5 percent extreme, 86°F (36°C) for the 10 percent, and 85°F (29°C) for the 20 percent.[65]

Table 30. Highest Recorded Temperature Extremes for the Naval Air Environment

Altitude		Height Above Sea Level				Pressure Alt.*	
		Temp.		Density	Density	Temp.	
Km	Ft × 10^3	°C	°F	Kg M^{-3}	Lb Ft^{-3}	°C	°F
0	0	51	124	1074 × 10^{-3}	669 × 10^{-4}	-	-
1	3.28	34	93	1040	648	34	93
2	6.56	26	79	934	582	24	77
4	13.1	16	61	780	486	14	57
6	19.7	2	36	635	396	0	32
8	26.2	-8	18	498	310	-10	14
10	32.8	-20	-4	415	259	-24	-11
12	39.4	-36	-33	303	189	-36	-33
14	45.9	-35	-31	192	120	-35	-31
16	52.5	-35	-31	117	73	-35	-31

Table 31. One Percent High Temperature Extremes for the Naval Air Environment

Altitude		Height Above Sea Level				Pressure Alt.*	
		Temp.		Density		Temp.	
Km	Ft × 10^3	°C	°F	Kg M^{-3}	Lb Ft^{-3}	°C	°F
0	0	48	118	1085 × 10^{-3}	676 × 10^{-4}	-	-
1	3.28	33	91	1057	659	33	91
2	6.56	25	77	948	591	24	75
4	13.1	14	57	814	507	12	54
6	19.7	1	34	642	400	-2	28
8	26.2	-9	16	538	335	-14	7
10	32.8	-21	-6	422	263	-27	-17
12	39.4	-39	-38	340	212	-39	-38
14	45.9	-37	-35	221	138	-37	-35
16	52.5	-37	-35	138	86	-37	-35

*See Section IV. 1. for a discussion of pressure altitude.

Table 32. Supplementary High Temperature Extremes for the Naval Air Environment

Altitude		Height Above Sea Level						Pressure Altitude*					
		5%		10%		20%		5%		10%		20%	
Km	Ft. × 10^3	°C	°F	°C	°F	°C	°F	°C	°F	°C	°F	°C	°F
0	0	46	115	45	113	43	109	-	-	-	-	-	-
1	3.28	32	90	31	88	31	88	32	90	31	88	31	88
2	6.56	24	75	23	73	23	73	23	73	22	72	22	72
4	13.1	12	54	11	52	11	52	10	50	9	48	9	48
6	19.7	0	32	-1	30	-1	30	-3	27	-4	25	-4	25
8	26.2	-10	14	-11	12	-11	12	-15	5	-16	3	-16	3
10	32.8	-22	-8	-23	-9	-23	-9	-28	-18	-30	-22	-30	-22
12	39.4	-40	-40	-42	-44	-43	-45	-40	-40	-42	-44	-43	-45
14	45.9	-38	-36	-39	-38	-40	-40	-38	-36	-39	-38	-40	-40
16	52.5	-39	-38	-39	-38	-40	-40	-39	-38	-39	-38	-40	-40

*See Section IV. 1. for a discussion of pressure altitude.

Table 33. Likely Densities Associated With the 5, 10, and 20 Percent High Temperature Extremes for the Naval Air Environment

		5%	10%	20%
Km	Ft × 10^3	Kg M^{-3}	Kg M^{-3}	Kg M^{-3}
0	0	1093×10^{-3}	1097×10^{-3}	1105×10^{-3}
1	3.28	1072	1085	1085
2	6.56	962	977	977
4	13.1	848	880	880
6	19.7	651	660	660
8	26.2	555	581	581
10	32.8	430	440	440
12	39.4	352	374	386
14	45.9	236	252	267
16	52.5	160	160	171

2.1.2 LOW TEMPERATURE

2.1.2.1 Lowest Recorded

The lowest recorded temperatures are given in Table 34 for both altitudes above sea level and pressure altitude. Likely densities accompanying temperatures at altitudes above sea level are also provided; departures in these values of up to ±15 percent are possible.

Table 34. Lowest Recorded Temperature Extremes for the Naval Air Environment

Altitude		Height Above Sea Level				Pressure Alt.*	
		Temp.		Density		Temp.	
Km	Ft × 10^3	°C	°F	Kg $M^{-3} \times 10^{-3}$	Lb $Ft^{-3} \times 10^{-4}$	°C	°F
0	0	-38	-36	1554	968	-	-
1	3.28	-31	-24	1292	805	-33	-27
2	6.56	-32	-26	1105	688	-34	-29
4	13.1	-40	-40	798	497	-41	-42
6	19.7	-47	-53	650	405	-48	-54
8	26.2	-58	-72	503	313	-60	-76
10	32.8	-70	-94	420	262	-70	-94
12	39.4	-75	-103	294	183	-74	-101
14	45.9	-76	-105	230	143	-78	-109
16	52.5	-87	-125	161	100	-87	-125

*See Section IV. 1. for a discussion of pressure altitude.

2.1.2.2 Operations

One percent extreme temperatures are given in Table 35 at altitudes above sea level and pressure altitude. Likely densities which accompany temperature extremes at altitudes above sea level are provided; departures in these values of up to ±15 percent are possible. The temperature value at 0 km in Table 35 is for operations in cold ports. For equipment only required to operate at sea, the criteria at 0 km is 7°F (-14°C).[65]

The 5, 10, and 20 percent extremes are given in Table 36 and accompanying densities for heights above sea level in Table 37. The temperature values at 0 km in Table 36 are for operations in cold ports. For equipment required only to operate at sea, the criteria at 0 km are 14°F (-10°C) for the 5 percent extreme, 18°F (-8°C) for the 10 percent, and 21°F (-6°C) for the 20 percent.[65]

Table 35. One Percent Low Temperature Extremes for the Naval Air Environment

Altitude		Height Above Sea Level				Pressure Alt. *	
		Temp.		Density		Temp.	
Km	Ft × 10^3	°C	°F	Kg $M^3 \times 10^3$	Lb $Ft^3 \times 10^4$	°C	°F
0	0	-34	-29	1525	950	-	-
1	3.28	-29	-20	1264	787	-31	-24
2	6.56	-31	-24	1080	673	-33	-27
4	13.1	-39	-38	787	490	-40	-40
6	19.7	-46	-51	633	394	-47	-53
8	26.2	-56	-69	485	302	-58	-72
10	32.8	-69	-92	405	252	-69	-92
12	39.4	-74	-101	280	174	-73	-99
14	45.9	-75	-103	210	131	-77	-107
16	52.5	-86	-123	143	89	-86	-123

Table 36. Supplementary Low Temperature Extremes for the Naval Air Environment

		Altitude Above Sea Level						Pressure Altitude*					
Altitude		5%		10%		20%		5%		10%		20%	
Km	Ft× 10^3	°C	°F	°C	°F	°C	°F	°C	°F	°C	°F	°C	°F
0	0	-28	-18	-25	-13	-22	-8	-	-	-	-	-	-
1	3.28	-24	-11	-23	-9	-21	-6	-26	-15	-25	-13	-23	-9
2	6.56	-28	-18	-27	-17	-25	-13	-30	-22	-29	-20	-27	-17
4	13.1	-37	-35	-36	-33	-35	-31	-38	-36	-37	-35	-36	-33
6	19.7	-42	-44	-41	-42	-40	-40	-41	-42	-40	-40	-38	-36
8	26.2	-55	-67	-52	-62	-50	-58	-57	-71	-54	-65	-53	-63
10	32.8	-65	-85	-64	-83	-62	-80	-65	-85	-64	-83	-62	-80
12	39.4	-70	-94	-69	-92	-67	-89	-69	-92	-68	-90	-66	-87
14	45.9	-73	-99	-72	-98	-71	-96	-75	-103	-74	-101	-73	-99
16	52.5	-84	-119	-83	-117	-82	-116	-84	-119	-83	-117	-82	-116

*See Section IV. 1. for a discussion of pressure altitude.

Table 37. Likely Densities Associated With the 5, 10, and 20 Percent Low Temperature Extremes for the Naval Air Environment

		5%	10%	20%
Km	Ft × 10^3	Kg M^{-3}	Kg M^{-3}	Kg M^{-3}
0	0	1483 × 10^{-3}	1462 × 10^{-3}	1442 × 10^{-3}
1	3.28	1200	1187	1163
2	6.56	1015	998	968
4	13.1	765	754	741
6	19.7	573	560	545
8	26.2	475	447	429
10	32.8	350	335	307
12	39.4	220	206	181
14	45.9	170	152	134
16	52.5	110	109	100

2.2 Low Absolute Humidity

2.2.1 LOWEST RECORDED

Not available.

2.2.2 OPERATIONS

Not available.

IV. Extremes for Worldwide Air Environment

1. SURFACE TO 98,400 FT (30 km)

The climatological information presented in this section was provided, except where noted, by the USAF Environmental Technical Applications Center (ETAC) in four separate documents. The first of these[52] provided the initial information. The last three[68,69,70] provided improvements to the first report and also provided additional information.

Only operational extremes are presented in this section as the withstanding concept is not applicable in the upper air; that is, military equipment will not be stored or be in a standby status in the free atmosphere.

After a literature survey, a selection was made of areas most favorable for occurrence of extreme values. A list of radiosonde stations* located in or near

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*Stations that launch balloons which telemeter back to earth pressure, temperature, and humidity of the free air. By tracking such balloons, winds/wind shears are also determined.

68. Richard, O. E. (1972 Changes in 1-30 Km Data for MIL-STD-210B letter of 19 Sep 1972 from ETAC/EN (Richard) to AFCRL/LKI (Sissenwine).

69. Snelling, H. J. (1973) Coincident Temperature-Density Values for MIL-STD-210B letter from ETAC(EN) of 5 Jan 1973 to AFCRL (LKI).

70. Richard, O. E. (1973) Changes in Temperature at Pressure Altitude Tables and Dew Point Tables. Personal correspondence ETAC/EN (O. E. Richard) of 23 Jan 1973 to AFCRL/LKI (N. Sissenwine).

these areas was made and data for these stations processed. Data were summarized in the form of frequency distributions for temperature, dew point, wind speed, density, and pressure for the month with the most extreme weather conditions for these parameters.

The selection of the area or areas with the most extreme conditions, as they pertained to a particular element and the selection of the month or year at which these extreme conditions might be expected to occur, was accomplished subjectively by ETAC. The fact that the extreme conditions do not necessarily occur directly over a particular radiosonde site was noted. Adjustments were made to the observed data to more correctly represent the worldwide extreme conditions when deemed appropriate.

ETAC attempted to use the longest and most recent period of record available. For most stations, only about five years of data* were readily available in an acceptable format (complete period of record, data at a sufficient number of intervals) for summarization which would result in reliable statistics. Only data from standard meteorological pressure levels had been recorded for many overseas stations. With the increased distance between standard levels, especially above 700 mb, "straight line" extrapolating procedures introduced the ever-increasing possibility of error if these data were used. In addition, a number of stations had broken periods of record which did not appear to be dependable. In both of these cases, ETAC felt that the reliability sought from this study could not be obtained from such data. On several occasions substitute stations had to be used. Records to altitudes above, approximately, 24 km were incomplete; so a more thorough evaluation of these data than the data at lower levels was required. This was accomplished by comparison with data from nearby stations to attempt to establish the validity of the extreme based on a station with more complete data, as well as by spatial analysis.

Extremes are presented both at altitudes† above sea level and at pressure altitudes. Information at geometric altitudes is applicable in missile design whereas information at pressure altitudes is applicable in aircraft design since aircraft generally fly on given pressure altitude surfaces. Pressure altitude is the geopotential height in the Standard Atmosphere corresponding to a given pressure. The heights given by most altimeters are based on the relationship between pressure and height in the Standard Atmosphere. Since atmospheric conditions

*Usually taken twice a day.

†Actually the heights given are geopotential heights, but for design purposes these may be considered geometric heights above sea level; for instance at 30 km, the difference between geopotential and geometric heights is 143 m, and less than that at lower elevations.

are seldom standard, aircraft flying at a given pressure altitude may be at significantly different true altitudes above sea level; an aircraft flying at a constant pressure altitude may be ascending, descending, or flying level.

Highest/lowest recorded and 1, 5, 10, and 20 percent extremes are provided for the 1-km level and for each even kilometer level from 2 to 30 km for each weather element.* These percent extremes are based on observed extreme values or are estimates based on observed values and are not extrapolated extremes obtained assuming a normal (or any other) distribution for the values of a given element (see Section I. 2. 3). Because upper atmospheric observations are not routinely taken 24 hours per day, but usually only 2 times per day, the percent extremes do not strictly represent the number of hours per month that the value of a given element is equalled or surpassed as discussed in Section I. 2. 3. However, since diurnal cycles in the free air below 30 km are small, the distribution as obtained from summaries of original sounding data for each kilometer level for the extreme month and location selected are considered as fairly representative of percent extremes as defined in Section I. 2. 3.

A comparison was made between the various locations selected in order to arrive at a final most severe extreme for each level. When it was determined that the extreme condition existed either between two stations having sounding data or displaced from a sounding station, extrapolation through spatial analysis and/or subjective evaluation was accomplished in order to obtain a worldwide extreme value for that element.

For each percent extreme and altitude for which an extreme value has been identified, Richard and Snelling[52] also list the geographical location of the extreme. Locations of percentile values for a particular element may vary from altitude to altitude. Also, the extreme values may occur in different months for different percent extremes and height levels for the same element.

Although the percent extremes given in this section are believed to be the best available, there are some limiting factors: (a) the location of upper air sounding stations points may not be optimum; (b) the available period of record may not be representative; (c) the format in which the data were stored and in which the extremes are presented may sometimes exclude extremes; (d) and the recording instruments have limitations. It is conceivable that more extreme values may later be determined. In spite of these limitations, the extremes furnished are considered to be within desired accuracy in most cases.

*Values for the 0 km level may be obtained from Section II.

1.1 Temperature

In the following sections, a mean density associated with the temperature extremes at altitudes above sea level are also given.

1.1.1 HIGH TEMPERATURE

In the lower levels of the atmosphere the warmest temperatures are found over northern Africa, the Middle East, and India with the exception of the 2-km level where warmest temperatures generally occur in the vicinity of Colorado. These extremes in Colorado appear to be the result of surface heating since the ground surface in this area is approximately 1/2 km below the 2-km level. Above approximately 14 km, most of the warm extremes are observed at polar latitudes.

1.1.1.1 Highest Recorded

Table 38 gives the highest observed temperatures by altitude. It can be seen that the highest value observed was 41°C at 1 km above sea level (over Algeria in July).

1.1.1.2 Operations

The 1, 5, 10, and 20 percent high temperature extremes are given in Tables 39, 40, 41, and 42 respectively.

1.1.2 LOW TEMPERATURE

1.1.2.1 Lowest Recorded

The lowest recorded atmospheric temperatures are given in Table 43.

1.1.2.2 Operations

The 1, 5, 10, and 20 percent low temperature extremes are given in Tables 44, 45, 46, and 47 respectively.

1.2 Humidity

Problems produced near the surface by high and low atmospheric water vapor concentrations were discussed in Section II. 2.

Aloft, high water vapor concentrations cause problems in satellite and missile tracking by attenuating infrared radiation, in cabin environment control, and in radar tracking through effects on the index of refraction. No design problems related to very low water vapor concentrations have been recognized. However, for altitudes up to which complete distributions are available, 8 km low dewpoints have been tabulated.

Table 38. Highest Recorded Temperature for the Worldwide Air Environment – 1 to 30 km

	Altitude Above Sea Level						Pressure Altitude		
	Temperature			Density (kg/m^3)			Temperature		
Altitude (km)	Location (Area)	Value (°C)	Mo.	Mean	Maximum	Minimum	Location (Area)	Value (°C)	Mo.
1	Algeria	41	Jul	1.018	1.018	1.018	Algeria	40	Jul
2	Mid-West U.S.	32	Jul	.916	.917	.914	Saudi Arabia	31	Aug
4	NW India	19	Jul	.762	.765	.760	NW India	19	Jul
6	NW India	8	Jul	.611	.611	.611	NW India	6	Jul
8	NW India	-4	Jul	.499	.500	.495	NW India	-4	Jul
10	NW India	-13	Jul	.393	.393	.393	NW India	-18	Jul
12	NW India	-22	Jul	.316	.316	.316	NW India	-27	Jul
14	NW India	-30	Jul	.208	.208	.208	NW India	-34	Jul
16	Franz Josef Land	-35	Jul	.156	.156	.156	Franz Josef Land	-35	Jul
18	Franz Josef Land	-35	Jul	.118	.118	.118	Franz Josef Land	-34	Jul
20	Franz Josef Land	-33	Jul	.087	.087	.087	Franz Josef Land	-33	Jul
22	NW Greenland	-34	Jul	.065	.065	.065	NWT Canada	-36	Jul
24	NWT Canada	-33	Jul	.048	.048	.048	NWT Canada	-31	Jul
26	NWT Canada	-31	Jul	.036	.036	.036	NWT Canada	-32	Jul
28	NWT Canada	-32	Jul	.027	.027	.027	NWT Canada	-30	Jul
30	NWT Canada	-28	Jul	.020	.020	.020	NWT Canada	-28	Jul

Table 39. One Percent High Temperature Extremes for the Worldwide Air Environment – 1 to 30 km

	Altitude Above Sea Level						Pressure Altitude		
	Temperature			Density (kg/m^3)			Temperature		
Altitude (km)	Location (Area)	Value (°C)	Mo.	Mean	Maximum	Minimum	Location (Area)	Value (°C)	Mo.
1	Algeria	40	Jul	1.007	1.026	1.001	Algeria	39	Jul
2	Mid-West U.S.	30	Jul	.919	.924	.913	Saudi Arabia	29	Aug
4	NW India	17	Jul	.757	.758	.756	NW India	16	Jul
6	NW India	6	Jul	.613	.614	.612	NW India	4	Jul
8	NW India	-5	Jul	.497	.502	.496	NW India	-7	Jul
10	NW India	-13	Jul	.397	.400	.393	NW India	-18	Jul
12	NW India	-22	Jul	.317	.318	.316	NW India	-27	Jul
14	NW India	-30	Jul	.210	.210	.210	NW India	-34	Jul
16	Franz Josef Land	-37	Jul	.159	.159	.158	Franz Josef Land	-37	Jul
18	Franz Josef Land	-37	Jul	.119	.119	.119	Franz Josef Land	-38	Jul
20	Franz Josef Land	-37	Jul	.087	.087	.087	Franz Josef Land	-37	Jul
22	Franz Josef Land	-37	Jul	.067	.068	.066	Franz Josef Land	-37	Jul
24	NWT Canada	-37	Jul	.049	.050	.048	NWT Canada	-36	Jul
26	NWT Canada	-34	Jul	.036	.036	.036	NWT Canada	-34	Jul
28	NWT Canada	-32	Jul	.027	.027	.027	NWT Canada	-30	Jul
30	NWT Canada	-30	Jul	.020	.020	.020	NWT Canada	-30	Jul

Table 40. Five Percent High Temperature Extremes for the Worldwide Air Environment – 1 to 30 km

	Altitude Above Sea Level						Pressure Altitude		
	Temperature			Density (kg/m^3)			Temperature		
Altitude (km)	Location (Area)	Value (°C)	Mo.	Mean	Maximum	Minimum	Location (Area	Value (°C)	Mo.
1	Algeria	39	Jul	1.007	1.009	1.003	Algeria	38	Jul
2	Mid-West U.S.	29	Jul	.922	.930	.914	Saudi Arabia	27	Aug
4	NW India	14	Jul	.768	.770	.765	NW India	13	Jul
6	NW India	4	Jul	.616	.619	.614	NW India	1	Jul
8	NW India	-6	Jul	.501	.502	.500	NW India	-11	Jul
10	NW India	-17	Jul	.400	.402	.397	NW India	-23	Jul
12	NW India	-24	Jul	.320	.322	.317	NW India	-32	Jul
14	NW India	-35	Jul	.213	.218	.210	NW India	-37	Jul
16	Franz Josef Land	-39	Jul	.161	.165	.158	Franz Josef Land	-39	Jul
18	Franz Josef Land	-38	Jul	.120	.122	.118	Franz Josef Land	-39	Jul
20	Franz Josef Land	-38	Jul	.090	.093	.088	Franz Josef Land	-39	Jul
22	Franz Josef Land	-38	Jul	.067	.068	.066	Franz Josef Land	-38	Jul
24	NWT Canada	-38	Jul	.049	.050	.048	NWT Canada	-38	Jul
26	NWT Canada	-37	Jul	.036	.037	.036	NWT Canada	-36	Jul
28	NWT Canada	-34	Jul	.027	.027	.027	NWT Canada	-34	Jul
30	NWT Canada	-31	Jul	.020	.020	.020	NWT Canada	-30	Jul

Table 41. Ten Percent High Temperature Extremes for the Worldwide Air Environment – 1 to 30 km

	Altitude Above Sea Level						Pressure Altitude		
	Temperature			Density (kg/m^3)			Temperature		
Altitude (km)	Location (Area)	Value (°C)	Mo.	Mean	Maximum	Minimum	Location (Area)	Value (°C)	Mo.
1	Algeria	38	Jul	1.009	1.017	1.003	Algeria	37	Jul
2	Mid-West U.S.	28	Jul	.925	.932	.918	Saudi Arabia	26	Aug
4	NW India	13	Jul	.767	.774	.763	NW India	11	Jul
6	NW India	3	Jul	.622	.628	.616	NW India	-1	Jul
8	NW India	-9	Jul	.505	.506	.499	NW India	-13	Jul
10	NW India	-19	Jul	.403	.404	.402	NW India	-25	Jul
12	NW India	-30	Jul	.321	.326	.316	NW India	-33	Jul
14	NW India	-36	Jul	.215	.232	.211	NW India	-38	Jul
16	Franz Josef Land	-39	Jul	.161	.165	.158	Franz Josef Land	-39	Jul
18	Franz Josef Land	-39	Jul	.120	.125	.119	Franz Josef Land	-39	Jul
20	Franz Josef Land	-39	Jul	.090	.094	.088	Franz Josef Land	-39	Jul
22	Franz Josef Land	-38	Jul	.067	.068	.066	Franz Josef Land	-39	Jul
24	NWT Canada	-39	Jul	.049	.050	.048	NWT Canada	-38	Jul
26	NWT Canada	-37	Jul	.036	.037	.036	NWT Canada	-37	Jul
28	NWT Canada	-35	Jul	.027	.027	.026	NWT Canada	-34	Jul
30	NWT Canada	-32	Jul	.020	.020	.020	NWT Canada	-31	Jul

Table 42. Twenty Percent High Temperature Extremes for the Worldwide Air Environment – 1 to 30 km

	Altitude Above Sea Level						Pressure Altitude		
	Temperature			Density (kg/m^3)			Temperature		
Altitude (km)	Location (Area)	Value (°C)	Mo.	Mean	Maximum	Minimum	Location (Area)	Value (°C)	Mo.
1	Algeria	34	Jul	1.012	1.015	1.004	Algeria	34	Jul
2	Mid-West U.S.	27	Jul	.928	.936	.922	Saudi Arabia	25	Aug
4	NW India	12	Jul	.772	.776	.765	NW India	10	Jul
6	NW India	0	Jul	.625	.626	.623	NW India	-2	Jul
8	NW India	-11	Jul	.508	.512	.507	NW India	-14	Jul
10	NW India	-20	Jul	.403	.405	.401	NW India	-26	Jul
12	NW India	-31	Jul	.320	.324	.319	NW India	-37	Jul
14	Franz Josef Land	-40	Jul	.216	.229	.212	Franz Josef Land	-40	Jul
16	Franz Josef Land	-40	Jul	.161	.169	.158	Franz Josef Land	-40	Jul
18	Franz Josef Land	-40	Jul	.122	.125	.119	Franz Josef Land	-40	Jul
20	Franz Josef Land	-40	Jul	.090	.093	.089	Franz Josef Land	-40	Jul
22	Franz Josef Land	-39	Jul	.068	.069	.067	Franz Josef Land	-40	Jul
24	NWT Canada	-39	Jul	.049	.050	.048	NWT Canada	-39	Jul
26	NWT Canada	-38	Jul	.036	.037	.036	NWT Canada	-37	Jul
28	NWT Canada	-36	Jul	.027	.027	.026	NWT Canada	-35	Jul
30	NWT Canada	-33	Jul	.020	.020	.020	NWT Canada	-32	Jul

Table 43. Lowest Recorded Temperature Extremes for the Worldwide Air Environment – 1 to 30 km

	Altitude Above Sea Level						Pressure Altitude		
	Temperature			Density (kg/m^3)			Temperature		
Altitude (km)	Location (Area	Value (°C)	Mo.	Mean	Maximum	Minimum	Location (Area)	Value (°C)	Mo.
1	N-Cen Siberia	-54	Jan	1.419	1.419	1.419	N-Cen Siberia	-56	Jan
2	NWT Canada	-47	Jan	1.147	1.147	1.147	NWT Canada	-47	Jan
4	NWT Canada	-53	Jan	.899	.899	.899	NWT Canada	-51	Jan
6	NWT Canada	-61	Jan	.681	.681	.681	NWT Canada	-60	Jan
8	N-Cen Siberia	-68	Jan	.510	.510	.510	N-Cen Siberia	-64	Jan
10	N-Cen Siberia	-74	Jan	.407	.407	.407	N-Cen Siberia	-72	Jan
12	NWT Canada	-80	Jan	.314	.314	.314	NWT Canada	-77	Jan
14	NWT Canada	-77	Jan	.218	.218	.218	Singapore	-78	Jul
16	Singapore	-87	Jul	.208	.208	.208	Singapore	-87	Jul
18	Canal Zone	-88	Jan	.143	.143	.143	Kenya	-85	Oct
20	NWT Canada	-85	Jan	.078	.078	.078	NWT Canada	-83	Jan
22	NWT Canada	-85	Jan	.054	.054	.054	NWT Canada	-85	Jan
24	NWT Canada	-86	Jan	.038	.039	.038	NWT Canada	-85	Jan
26	NWT Canada	-84	Jan	.029	.029	.028	NWT Canada	-85	Jan
28	NWT Canada	-83	Jan	.020	.020	.020	NWT Canada	-85	Jan
30	NWT Canada	-81	Jan	.011	.011	.011	NWT Canada	-85	Jan

Table 44. One Percent Low Temperature Extremes for the Worldwide Air Environment — 1 to 30 km

	Altitude Above Sea Level						Pressure Altitude		
	Temperature			Density (kg/m^3)			Temperature		
Altitude (km)	Location (Area)	Value (°C)	Mo.	Mean	Maximum	Minimum	Location (Area)	Value (°C)	Mo.
1	N-Cen Siberia	-53	Jan	1.408	1.408	1.408	N-Cen Siberia	-55	Jan
2	NWT Canada	-41	Jan	1.132	1.142	1.123	N-Cen Siberia	-42	Jan
4	NWT Canada	-48	Jan	.868	.870	.866	NWT Canada	-46	Jan
6	NWT Canada	-56	Jan	.675	.690	.656	NWT Canada	-55	Jan
8	N-Cen Siberia	-66	Jan	.523	.523	.523	N-Cen Siberia	-64	Jan
10	N-Cen Siberia	-74	Jan	.407	.407	.407	N-Cen Siberia	-71	Jan
12	NWT Canada	-73	Jan	.297	.298	.295	NWT Canada	-72	Jan
14	NWT Canada	-75	Jan	.214	.218	.208	Singapore	-77	Jul
16	Singapore	-86	Jul	.206	.208	.204	Singapore	-86	Jul
18	Canal Zone	-86	Jan	.143	.143	.143	Kenya	-85	Oct
20	NWT Canada	-84	Jan	.078	.078	.077	NWT Canada	-83	Jan
22	NWT Canada	-84	Jan	.054	.059	.054	NWT Canada	-85	Jan
24	NWT Canada	-85	Jan	.038	.039	.038	NWT Canada	-85	Jan
26	NWT Canada	-84	Jan	.029	.029	.028	NWT Canada	-85	Jan
28	NWT Canada	-83	Jan	.020	.020	.020	NWT Canada	-85	Jan
30	NWT Canada	-80	Jan	.011	.011	.011	NWT Canada	-84	Jan

Table 45. Five Percent Low Temperature Extremes for the Worldwide Air Environment — 1 to 30 km

	Altitude Above Sea Level						Pressure Altitude		
	Temperature			Density (kg/m^3)			Temperature		
Altitude (km)	Location (Area)	Value (°C)	Mo.	Mean	Maximum	Minimum	Location	Value	Mo.
1	N-Cen Siberia	-51	Jan	1.387	1.416	1.367	N-Cen Siberia	-54	Jan
2	NWT Canada	-36	Jan	1.122	1.156	1.092	N-Cen Siberia	-38	Jan
4	NWT Canada	-44	Jan	.864	.894	.837	NWT Canada	-43	Jan
6	NWT Canada	-54	Jan	.676	.597	.650	NWT Canada	-52	Jan
8	NWT Canada	-63	Jan	.520	.538	.503	NWT Canada	-61	Jan
10	NWT Canada	-69	Jan	.402	.421	.388	N-Cen Siberia	-68	Jan
12	NWT Canada	-70	Jan	.289	.322	.281	NWT Canada	-70	Jan
14	NWT Canada	-73	Jan	.210	.217	.195	Singapore	-76	Jul
16	Singapore	-84	Jul	.202	.206	.192	Singapore	-85	Jul
18	Canal Zone	-84	Jan	.143	.143	.143	Kenya	-82	Oct
20	NWT Canada	-83	Jan	.077	.079	.075	NWT Canada	-82	Jan
22	NWT Canada	-83	Jan	.055	.059	.053	NWT Canada	-84	Jan
24	NWT Canada	-83	Jan	.038	.040	.037	NWT Canada	-84	Jan
26	NWT Canada	-83	Jan	.028	.028	.028	NWT Canada	-84	Jan
28	NWT Canada	-81	Jan	.019	.019	.019	NWT Canada	-83	Jan
30	NWT Canada	-79	Jan	.010	.010	.010	NWT Canada	-83	Jan

Table 46. Ten Percent Low Temperature Extremes for the Worldwide Air Environment – 1 to 30 km

	Altitude Above Sea Level						Pressure Altitude		
	Temperature			Density (kg/m^3)			Temperature		
Altitude (km)	Location (Area)	Value (°C)	Mo.	Mean	Maximum	Minimum	Location (Area)	Value (°C)	Mo.
1	N-Cen Siberia	-50	Jan	1.390	1.415	1.366	N-Cen Siberia	-53	Jan
2	NWT Canada	-34	Jan	1.118	1.147	1.100	N-Cen Siberia	-36	Jan
4	NWT Canada	-42	Jan	.868	.890	.850	NWT Canada	-39	Jan
6	NWT Canada	-53	Jan	.676	.694	.645	NWT Canada	-51	Jan
8	NWT Canada	-63	Jan	.519	.537	.504	NWT Canada	-61	Jan
10	NWT Canada	-67	Jan	.394	.415	.370	N-Cen Siberia	-66	Jan
12	NWT Canada	-68	Jan	.283	.305	.264	NWT Canada	-67	Jan
14	NWT Canada	-72	Jan	.206	.215	.193	Singapore	-75	Jul
16	Singapore	-83	Jul	.200	.206	.190	Singapore	-84	Jul
18	Canal Zone	-82	Jan	.142	.145	.140	Kenya	-80	Oct
20	NWT Canada	-81	Jan	.077	.082	.072	NWT Canada	-81	Jan
22	NWT Canada	-82	Jan	.057	.059	.055	NWT Canada	-83	Jan
24	NWT Canada	-82	Jan	.039	.041	.037	NWT Canada	-83	Jan
26	NWT Canada	-81	Jan	.027	.028	.026	NWT Canada	-83	Jan
28	NWT Canada	-79	Jan	.019	.019	.019	NWT Canada	-82	Jan
30	NWT Canada	-78	Jan	.010	.011	.009	NWT Canada	-81	Jan

Table 47. Twenty Percent Low Temperature Extremes for the Worldwide Air Environment – 1 to 30 km

	Temperature			Density (kg/m^3)			Temperature		
Altitude (km)	Location (Area)	Value (°C)	Mo.	Mean	Maximum	Minimum	Location (Area)	Value (°C)	Mo.
1	N-Cen Siberia	-49	Jan	1.400	1.410	1.383	N-Cen Siberia	-52	Jan
2	NWT Canada	-31	Jan	1.110	1.130	1.096	N-Cen Siberia	-33	Jan
4	NWT Canada	-40	Jan	.864	.879	.834	NWT Canada	-37	Jan
6	NWT Canada	-51	Jan	.671	.683	.660	NWT Canada	-48	Jan
8	NWT Canada	-61	Jan	.518	.534	.490	NWT Canada	-59	Jan
10	NWT Canada	-65	Jan	.391	.406	.373	N-Cen Siberia	-64	Jan
12	NWT Canada	-67	Jan	.283	.322	.263	NWT Canada	-65	Jan
14	NWT Canada	-70	Jan	.205	.230	.197	Singapore	-73	Jul
16	Singapore	-82	Jul	.198	.200	.194	Singapore	-83	Jul
18	Canal Zone	-80	Jan	.140	.142	.138	Kenya	-79	Oct
20	NWT Canada	-79	Jan	.079	.083	.075	NWT Canada	-77	Jan
22	NWT Canada	-80	Jan	.055	.057	.053	NWT Canada	-79	Jan
24	NWT Canada	-80	Jan	.039	.042	.037	NWT Canada	-82	Jan
26	NWT Canada	-79	Jan	.027	.030	.026	NWT Canada	-82	Jan
28	NWT Canada	-77	Jan	.018	.018	.018	NWT Canada	-81	Jan
30	NWT Canada	-76	Jan	.012	.014	.011	NWT Canada	-79	Jan

As mentioned in Section II. 2, there are two categories of equipment problems related to atmospheric water vapor content: those associated with moisture content which can be described in terms of absolute humidity, dew point (frost point), or vapor pressure (all of which have a one-to-one correspondence) and mixing ratio; and those problems associated with relative humidity.

The first category, the amount of water in the air, is of primary concern in the operation of equipment. The second category, relative humidity, is usually related to corrosion and fungus during long-term exposure at fairly high temperatures, a "withstanding" problem. Only the operational problem, probability of occurrence of high and low dew points (frost points), is of concern for high altitudes and the subject of this section. However, an important operational exception, where relative humidity extremes aloft must be considered, is that of high voltage breakdown and leakage along insulators which results in malfunctions of electronic components. Such extremes should be provided in subsequent changes to MIL-STD-210. Relative humidities of 100 percent can occur at any altitude below the tropopause over the entire globe.

1.2.1 ABSOLUTE HUMIDITY

Readers interested in a general discussion of absolute humidity should read Section II. 2. 1. The absolute humidity extremes are presented in terms of the dew-point temperature since it has a one-to-one relationship with absolute humidity.

ETAC terminated tabulations of extreme dew-points at 8 km. Because of the limitations in accuracy of the humidity recording element of current radiosonde instruments, accurate measurements of dew (frost) points above 8 km have been achieved in only a limited number of experiments with specially designed instrumentation. Using such data Grantham and Sissenwine[21] have provided first estimates of high 1 percent dew (frost) points. These estimates and the data and procedure used to arrive at the estimates are discussed in Section 1. 2. 1. 1. 1 below.

1.2.1.1 High Absolute Humidity

ETAC surveyed the Atmospheric Humidity Atlas—Northern Hemisphere[20] for areas of high dew points. This pbblication confirmed the idea that areas with highest absolute humidities would be in the vicinity of the monsoonal flow over Southern Asia. Highest dew points were found embedded in the strong and deep monsoonal flow over India. These values were recorded during the height of the monsoon season—the month of July. Table 48 lists these extremes.

Above 8 km, 1 percent extremes of high dew (frost) points have been provided by Grantham and Sissenwine.[21] Starting about 10 km, measurements are limited to research data with specially designed instrumentation. These research data have been collected over only a few geographical areas; the samples are too small

Table 48. High Absolute Humidity (Dew Point) Extremes for the Worldwide Air Environment – 1 to 8 Km

Altitude Above Sea Level				Pressure Altitude			
Highest Recorded				Highest Recorded			
Altitude (Km)	Location (Area)	Value (°C)	Mo.	Height (km)	Location (Area)	Value (°C)	Mo.
1	N India	30	Jul	1	N India	30	Jul
2	N India	26	Jul	2	N India	26	Jul
4	N India	18	Jul	4	N India	18	Jul
6	NW India	3	Jul	6	N India	1	Jul
8	N India	-7	Jul	8	N India	-11	Jul
1% Probable				1% Probable			
1	N India	29	Jul	1	N India	29	Jul
2	N India	24	Jul	2	N India	24	Jul
4	NW India	16	Jul	4	N India	15	Jul
6	NW India	3	Jul	6	NW India	1	Jul
8	N India	-8	Jul	8	N India	-12	Jul
5% Probable				5% Probable			
1	N India	27	Jul	1	N India	27	Jul
2	N India	22	Jul	2	N India	22	Jul
4	N India	13	Jul	4	N India	12	Jul
6	N India	0	Jul	6	N India	-2	Jul
8	N India	-11	Jul	8	N India	-14	Jul
10% Probable				10% Probable			
1	N India	26	Jul	1	N India	26	Jul
2	NW India	21	Jul	2	NW India	21	Jul
4	N India	11	Jul	4	N India	10	Jul
6	N India	-1	Jul	6	N India	-3	Jul
8	N India	-12	Jul	8	N India	-15	Jul
20% Probable				20% Probable			
1	N India	25	Jul	1	N India	25	Jul
2	NW India	20	Jul	2	NW India	19	Jul
4	N India	9	Jul	4	N India	8	Jul
6	N India	-2	Jul	6	N India	-4	Jul
3	N India	-13	Jul	8	N India	-16	Jul

in number to provide reliable frequency distributions, and some of them are of questionable accuracy. These data limitations make it virtually impossible to arrive at true 1-percent probable extremes for altitudes at and above 10 km. Even rough estimates are difficult to make.

The Naval Research Laboratories conducted numerous high-level humidity measurements at Washington, D.C., Trinidad, and Kwajalein. The Air Force Cambridge Research Laboratories' Design Climatology Branch also conducted an intensive stratospheric humidity measurement program. The humidity element was an alpha-radiation frost-point hygrometer which was carried to altitudes up to 32 km by balloons launched from Chico, California. A "Mid-Latitude Humidity Profile" resulted from this program. This profile represented typical mid-latitude conditions over a year (not a true mean). It may have been very far from a 1-percent extreme absolute humidity profile, regardless of location, but at least it provided Grantham and Sissenwine with a shape of the vertical profile as a starting point for the 1-percent extreme profile.

The tropopause is known to be a moisture trap for water vapor originating at surface levels, since it is the coldest level above the surface and the frost point cannot exceed the temperature. Therefore, Grantham and Sissenwine decided that the highest humidity at about the 12 km (200-mb) level, which is in the troposphere at low- and mid-latitudes, would be observed in an area where near-saturation occurs in warm (polar) tropospheric air just below the tropopause. This area seemed to be in southern Russia, a location reasonably consistent with the movements of the humidity centers from lower altitudes. The upper 1-percent extreme frost point at 200 mb for July at 55°N 90°E was then determined as -43°C by assuming a 50-percent relative humidity with a previously determined 1-percent warm tropopause temperature. This 50-percent relative humidity is consistent with other results of humidity studies conducted for altitudes at and slightly below the polar tropopause level. By using the 5-percent warm tropopause temperature in an analogous procedure, the upper 5-percent frost point at about 12 km (200 mb) was determined to be -49°C.

The moisture source for high humidities in the 15 to 20 km level develops from a completely different physical phenomenon, cumulonimbus clouds, which reach these altitudes 1 percent of the time in certain areas. Assuming saturation in and adjacent to these clouds, the temperature profile can be considered as a dew-point profile. A July mean of the temperature soundings taken very near the periods of radar-observed echoes at these levels is considered as the 1-percent frost point envelope for altitudes between 15 and 20 km. Echoes do go higher than 20 km, but only at less than 1 percent of the time even in the worst months. Therefore, through the 20-km level, a fairly reliable basis is established for the

upper 1-percent frost-point envelope. Above this level, there are only the research observations discussed earlier, none of which were made over areas where high frost-point temperatures are expected. Also, observations were not obtained frequently enough to approximate the distribution even in the areas over which experiments were performed. However, there is one additional scientific fact on which extrapolation can be based – the determination that noctilucent clouds, which occur near altitudes of 80 km, are composed of ice-covered particles. Based on temperature measurements made in the presence and then in the absence of noctilucent clouds, plus the most accepted hypothesis on the formation and composition of these clouds, Grantham and Sissenwine[21] determined that a conservative value for the mixing ratio at 80 km is 5 ppm; that is, 5 grams of water vapor in a volume of 1,000,000 grams of dry air. The 80-km frost point for this assumption is about -122°C.

Based upon the assumption that there are no major water sources or sinks between the height to which tropospheric clouds penetrate the tropopause and the 80-km level, the 1-percent high frost-point envelope was then linearly extended from the 20-km value of -56°C to -122°C at 80 km.

For altitudes between 10 and 30 km these 1 percent frost points are:

Pressure Altitude (Km)	Estimated 1% Frost Point (°C)
10	-29.5
12	-45.0
14	-60.0
15	-66.0
16	-64.0
18	-60.0
20	-56.5
22	-59.0
24	-61.0
25	-62.0
26	-63.0
28	-65.0
30	-67.5

These extremes, especially above 20 km, cannot be considered to have been statistically derived and are only first estimates of the 1-percent frost points. At the time that Grantham and Sissenwine prepared their report, no evidence supporting these values had appeared in the literature. Such evidence was uncovered shortly afterward. A temperature of about -57°C at 22 km was recorded during a display of unusually high clouds near White Sands in June 1969 and identified as the nacreous type, usually associated with strong westerly flow. (These may have been the blow off of cirrus from a cumulonimbus penetrating the tropopause over eastern Texas, since east winds are found at this altitude and season.) Altitude

was determined accurately by triangulation. Assuming saturation conditions at this altitude, this temperature is also the frost point.

It should be emphasized that these values cannot be interpreted as profiles, since values for the various altitudes may not correspond to one another in either time or space. It would not be unreasonable, however, to accept short portions of the envelope values, say 2-km intervals, as typical upper 1-percent frost-point profiles allowing for the disdontinuities at 15 and 20 km.

1.2.1.1.1 HIGHEST RECORDED

See Table 48.

1.2.1.1.2 OPERATIONS

See Table 48. The 1 percent values are primary goals in design.

1.2.1.2 Low Absolute Humidity

All the minimum values were found in the polar regions in the vicinity of northwest Canada. These minimum values occurred during the winter seasons. Table 49 lists these extremes.

1.2.1.2.1 LOWEST RECORDED

See Table 49.

1.2.1.2.2 OPERATIONS

See Table 49. The 1 percent values are primary goals in design.

1.2.2 RELATIVE HUMIDITY

Not available.

1.3 Wind

1.3.1 WIND SPEED

Most knowledge of extremes of wind aloft has been acquired from indirect sources such as aircraft reports and cloud movements. Unfortunately, many of these extreme wind values have not been recorded. This dilemma results from the method by which winds aloft are normally recorded. When strong winds are occurring, the balloon-borne sensor may be blown out of range of the observing site before the maximum wind speed can be recorded.

The strongest winds aloft occur in the vicinity of the mid-latitude winter jet stream, at 10 to 12 km in altitude. Since the jet stream does not necessarily occur directly over a recording site and since it varies from season to season both in location and in strength, ETAC made a detailed study of jet stream winds.

Table 49. Low Absolute Humidity (Dew Point) Extremes for the Worldwide Air Environment – 1 to 8 Km

Altitude Above Sea Level				Pressure Altitude			
Lowest Recorded				Lowest Recorded			
Altitude (Km)	Location (Area)	Value (°C)	Mo.	Height (Km)	Location (Area)	Value (°C)	Mo.
1	NWT Canada	-51	Jan	1	NWT Canada	-51	Jan
2	NWT Canada	-53	Jan	2	NWT Canada	-53	Jan
4	NWT Canada	-58	Jan	4	NWT Canada	-57	Jan
6	NWT Canada	-66	Jan	6	NWT Canada	-66	Jan
8	NWT Canada	-71	Jan	8	NWT Canada	-68	Jan
	1% Probable				1% Probable		
1	NWT Canada	-50	Jan	1	NWT Canada	-50	Jan
2	NWT Canada	-51	Jan	2	NWT Canada	-50	Jan
4	NWT Canada	-56	Jan	4	NWT Canada	-54	Jan
6	NWT Canada	-65	Jan	6	NWT Canada	-61	Jan
8	NWT Canada	-71	Jan	8	NWT Canada	-68	Jan
	5% Probable				5% Probable		
1	NWT Canada	-42	Jan	1	NWT Canada	-42	Jan
2	NWT Canada	-45	Jan	2	NWT Canada	-44	Jan
4	NWT Canada	-52	Jan	4	NWT Canada	-51	Jan
6	NWT Canada	-61	Jan	6	NWT Canada	-58	Jan
8	NWT Canada	-70	Jan	8	NWT Canada	-67	Jan
	10% Probable				10% Probable		
1	NWT Canada	-40	Jan	1	NWT Canada	-40	Jan
2	NWT Canada	-42	Jan	2	NWT Canada	-41	Jan
4	NWT Canada	-51	Jan	4	NWT Canada	-49	Jan
6	NWT Canada	-60	Jan	6	NWT Canada	-57	Jan
8	NWT Canada	-69	Jan	8	NWT Canada	-66	Jan
	20% Probable				20% Probable		
1	NWT Canada	-37	Jan	1	NWT Canada	-37	Jan
2	NWT Canada	-39	Jan	2	NWT Canada	-38	Jan
4	NWT Canada	-49	Jan	4	NWT Canada	-47	Jan
6	NWT Canada	-59	Jan	6	NWT Canada	-56	Jan
8	NWT Canada	-68	Jan	8	NWT Canada	-65	Jan

It was concluded that jet-stream winds in all probability did not make up 1 percent of the maximum winds at any one location during any month.

USAF SAC Manual 105-2, Vol. 2 was used to assist in identifying the most probable regions of the globe for the occurrence of extreme wind values. Although a Southern Hemisphere jet stream has been suspected, little is known about it. Due to the large expanse of ocean between 35 and 65°S and the sparsity of winds-aloft reporting stations in these latitudes, it has been difficult to determine maximum wind values for the Southern Hemisphere. From the winds-aloft information studied, maximum wind speeds in the Southern Hemisphere appear to be less than those in the Northern Hemisphere.

Data summaries for 23 stations in the Northern Hemisphere were selected for inspection, and from this data Tables 50 through 54 were prepared.

The strongest winds to 6 km are generally located in the vicinity of Iceland. Above 6 km the extremes shift to southern Japan where the strongest jet streams in the world are experienced. At 8 km, an absolute extreme of 129 mps was observed at Amsterdam Island in the Indian Ocean in the month of May. This was the strongest worldwide wind observed at this altitude and is an exception to the general wind pattern. Wind extremes reach a maximum at about 12 km, or approximately the level of the core of the jet stream. Above 12 km the wind velocities decrease to a secondary minimum (the primary minimum is at the surface) between 18 and 20 km before increasing steadily again to 30 km. The area of maximum winds shifts away from the vicinity of the jet stream over Japan above 18 km. At these high altitudes, the maximum winds appear in a band which stretches from Eastern Siberia to the vicinity of Iceland. It was difficult identifying values at the western limit of these strong winds due to the very limited samples of wind data from Siberian stations. The extreme winds at high altitudes for the 5, 10, and 20 percent extremes are observed over northern Alaska, while for the 1 percent extreme and absolute values, they are observed primarily in the vicinity of Iceland.

1.3.1.1 Highest Recorded

The highest recorded wind speed up to 30 km is 153 mps, observed at a height of 10 km over Japan. Highest values for each altitude are provided in Table 50.

1.3.1.2 Operations

The 1 percent probable highest wind values are given in Table 51. The maximum, 110 mps, occurs at a geopotential height and pressure altitude of 12 km. The 5, 10, and 20 percent extreme wind speeds are given in Tables 52, 53, and 54 respectively.

Table 50. Highest Recorded Wind Speed Extremes for for the Worldwide Air Environment – 1 to 30 Km

Altitude Above Sea Level			
Altitude (Km)	Location (Area)	Value (mps)	Month
1	Iceland	60	Feb
2	Iceland	57	Feb
4	Northern North Atlantic	76	Jan
6	Northern North Atlantic	92	Jan
8	Indian Ocean	129	May
10	Central Japan	153	Dec
12	Central Japan	140	Mar
14	Southern Japan	110	Jan
16	Southern Japan	93	Jan
18	Northern Japan	74	Jan
20	Iceland	118	Feb
22	Iceland	102	Feb
24	Iceland	118	Jan
26	Iceland	116	Feb
28	Northern Greenland	118	Feb
30	Northern Greenland	130	Feb

Pressure Altitudes			
Height (Km)	Location (Area)	Value (mps)	Month
1	Eastern North Pacific	48	Dec
2	Iceland	46	Feb
4	Iceland	53	Feb
6	Southern Japan	80	Jan
8	Indian Ocean	110	May
10	Central Japan	150	Dec
12	Central Japan	140	May
14	Southern Japan	108	Jan
16	Southern Japan	93	Jan
18	Northern Japan	72	Jan
20	Iceland	107	Feb
22	Iceland	90	Feb
24	Iceland	97	Jan
26	Iceland	112	Feb
28	Iceland	134	Jan
30	Iceland	113	Jan

Table 51. One Percent Wind Speed Extremes
for the Worldwide Air Environment – 1 to 30 Km

Altitude Above Sea Level			
Altitude (Km)	Location (Area)	Value (mps)	Month
1	Iceland	43	Feb
2	Iceland	45	Feb
4	Northern North Atlantic	53	Jan
6	Northern North Atlantic	73	Jan
8	Northern Japan	87	Jan
10	Southern Japan	100	Jan
12	Southern Japan	110	Jan
14	Southern Japan	93	Jan
16	Southern Japan	74	Jan
18	Northern Japan	73	Jan
20	Northern Alaska	76	Jan
22	Northern Alaska	84	Jan
24	Iceland	88	Jan
26	Iceland	94	Jan
28	Northern Greenland	102	Feb
30	Northern Greenland	121	Feb

Pressure Altitudes			
Height (Km)	Location (Area)	Value (mps)	Month
1	Eastern North Pacific	37	Dec
2	Iceland	45	Feb
4	Iceland	50	Feb
6	Southern Japan	66	Jan
8	Southern Japan	83	Jan
10	Southern Japan	100	Jan
12	Southern Japan	110	Jan
14	Southern Japan	92	Jan
16	Southern Japan	72	Jan
18	Northern Japan	70	Jan
20	Northern Alaska	73	Jan
22	Northern Alaska	78	Jan
24	Iceland	87	Jan
26	Iceland	93	Feb
28	Northern Greenland	96	Jan
30	Northern Greenland	102	Jan

Table 52. Five Percent Wind Speed Extremes for the Worldwide Air Environment – 1 to 30 Km

Altitude Above Sea Level			
Altitude (Km)	Location (Area)	Value (mps)	Month
1	Northern North Atlantic	30	Jan
2	Iceland	34	Feb
4	Iceland	45	Feb
6	Northern Japan	58	Jan
8	Southern Japan	75	Jan
10	Southern Japan	89	Jan
12	Southern Japan	95	Jan
14	Southern Japan	81	Jan
16	Southern Japan	69	Jan
18	Northern Japan	56	Jan
20	Northern Alaska	56	Jan
22	Northern Alaska	65	Jan
24	Northern Alaska	76	Jan
26	Northern Alaska	80	Jan
28	Northern Alaska	91	Jan
30	Northern Alaska	98	Jan

Pressure Altitude			
Height (Km)	Location (Area)	Value (mps)	Month
1	Eastern North Pacific	29	Jan
2	Iceland	35	Feb
4	Iceland	42	Feb
6	Southern Japan	55	Jan
8	Southern Japan	74	Jan
10	Southern Japan	90	Jan
12	Southern Japan	94	Jan
14	Southern Japan	79	Jan
16	Southern Japan	68	Jan
18	Eastern Siberian Sea	53	Jan
20	Northern Alaska	55	Jan
22	Northern Alaska	63	Jan
24	Northern Alaska	75	Jan
26	Northern Alaska	79	Feb
28	Northern Alaska	84	Jan
30	Northern Alaska	89	Jan

Table 53. Ten Percent Wind Speed Extremes for the Worldwide Air Environment – 1 to 30 Km

Altitude Above Sea Level			
Altitude (Km)	Location (Area)	Value (mps)	Month
1	Northern North Atlantic	26	Jan
2	Northern North Atlantic	28	Jan
4	Southern Japan	37	Jan
6	Southern Japan	52	Jan
8	Southern Japan	70	Jan
10	Southern Japan	84	Jan
12	Southern Japan	89	Jan
14	Southern Japan	77	Jan
16	Southern Japan	66	Jan
18	Eastern Siberian Sea	53	Jan
20	Northern Alaska	52	Jan
22	Northern Alaska	62	Jan
24	Northern Alaska	69	Jan
26	Northern Alaska	74	Jan
28	Northern Alaska	84	Jan
30	Northern Alaska	89	Jan

Pressure Altitude			
Height (Km)	Location (Area)	Value (mps)	Month
1	Eastern North Pacific	26	Jan
2	Eastern North Pacific	27	Jan
4	Southern Japan	36	Jan
6	Southern Japan	51	Jan
8	Southern Japan	70	Jan
10	Southern Japan	84	Jan
12	Southern Japan	88	Jan
14	Southern Japan	75	Jan
16	Southern Japan	65	Jan
18	Eastern Siberian Sea	46	Jan
20	Northern Alaska	51	Jan
22	Northern Alaska	60	Jan
24	Northern Alaska	68	Jan
26	Northern Alaska	71	Jan
28	Northern Alaska	74	Jan
30	Northern Alaska	80	Jan

Table 54. Twenty Percent Wind Speed Extremes for the Worldwide Air Environment – 1 to 30 Km

Altitude Above Sea Level			
Altitude (Km)	Location (Area)	Value (mps)	Month
1	Northern North Atlantic	22	Jan
2	Eastern North Pacific	23	Dec
4	Northern Japan	33	Jan
6	Southern Japan	48	Jan
8	Southern Japan	62	Jan
10	Southern Japan	78	Jan
12	Southern Japan	84	Jan
14	Southern Japan	71	Jan
16	Southern Japan	57	Jan
18	Eastern Siberian Sea	48	Jan
20	Northern Alaska	44	Jan
22	Northern Alaska	52	Jan
24	Northern Alaska	61	Jan
26	Northern Alaska	65	Jan
28	Northern Alaska	72	Jan
30	Northern Alaska	77	Jan

Pressure Altitude			
Height (Km)	Location (Area)	Value (mps)	Month
1	Eastern North Pacific	21	Jan
2	Eastern North Pacific	23	Jan
4	Southern Japan	33	Jan
6	Southern Japan	47	Jan
8	Southern Japan	63	Jan
10	Southern Japan	78	Jan
12	Southern Japan	82	Jan
14	Southern Japan	69	Jan
16	Southern Japan	56	Jan
18	Eastern Siberian Sea	41	Jan
20	Northern Alaska	43	Jan
22	Northern Alaska	50	Jan
24	Northern Alaska	60	Jan
26	Northern Alaska	62	Jan
28	Northern Alaska	65	Jan
30	Northern Alaska	73	Jan

1.3.2 WIND SHEAR

Wind shears were computed over a 1-km thickness; from 500 m below specified levels to 500 m above. The north-south and east-west component of each wind observation was computed. Then, the absolute difference of each component between the bottom and top of the desired level was obtained. The shear was then determined as the magnitude of the vector sum of these two components.

Since strong shears have been experienced in the vicinity of the jet stream, it seemed most logical to start the investigation with those wind statistics at stations near the jet stream. Those stations with strongest winds utilized for the wind speed study and the mid-Atlantic coastal area of the United States were investigated. In all, 12 stations were studied.

ETAC compiled wind-shear extremes for only three stations with both the geopotential-height statistics and the pressure-altitude statistics. Extremes for the remaining nine stations were available for geopotential heights only.

An analysis of the differences between the geopotential-height wind shear and the pressure-altitude wind shear summarized data was made for the three stations having both summaries. Using these differences, for the most part, the pressure-altitude wind shears were determined from the geopotential-height wind shears. Wind-shear extremes are presented in Tables 55 through 59.

Extreme wind-shear values below approximately 4 km and above approximately 22 km are over the eastern United States or Iceland. Between 4 and 22 km extreme wind shear is centered over Japan in association with the strongest upper air flow in the world.

1.3.2.1 Highest Recorded

Highest values for each level are provided in Table 55.

3.2.2 OPERATIONS

One, five, ten, and twenty percent values are provided in Tables 56 through 59 respectively.

1.4 Precipitation

1.4.1 PRECIPITATION RATE[71]

Precipitation intensities for ground operation have been studied and extremes recommended in a special report,[34] a supporting background document for this MIL-STD-210B endeavor. The authors of that report are climatologists who were

71. Sissenwine, N. (1972) Extremes of Hydrometeors at Altitude for MIL-STD-210B, AFCRL, Air Force Surveys in Geophysics (manuscript).

able to infer nearly instant precipitation intensity pertinent to military design from the very large inventory of surface weather data that has as its basic utilization applications in agriculture and hydrology. Such an inventory of data is not available at altitudes applicable to most air operations.

Scientists most knowledgeable of water content in clouds and precipitation aloft are reluctant to specify extremes for specific calculated risks aloft since they do not have a sufficiently strong scientific inventory of data to defend such extremes. On the other hand, engineers very much less knowledgeable of precipitation conditions aloft and with far less qualifications than the scientists actually doing research on this problem, have over the past[60] and presently (in a draft revision of MIL-STD-810C, "Environmental Test Methods" dated 15 December 1972) had to specify precipitation extremes. The most recent test value of 12 in. in 5 min in this draft (6 mm/min) is double the world record 1-min rainfall.[8] In view of the urgency for realistic values and an overall responsibility for the scientific realism of MIL-STD-210B, Sissenwine[71] chose to determine best estimates of precipitation extremes aloft using best available information. He extrapolated upward surface climatological intensities with known probabilities, and improbable, but recorded extremes by utilizing the research information available from meteorologists specializing in cloud physics and radar meteorology. Table 60 summarizes his findings.

Extremes of most elements being provided in MIL-STD-210B for air operations will be useful in design but would not generally be critical for operations. An example of such an element could be extreme density at a given altitude. For most flight equipment, encountering a condition even greater than the extreme considered logical in design would probably usually result in an operation less satisfactory than desired but would not be catastrophic. This may not be true for some problems involving extremes of hydrometeors at altitude. Cloud and precipitation parti[illegible] liquid and ice, ingested into a jet engine could create excessive cooling due to [illegible]porization in the intake air compression chambers, causing flameout and a consequent crash. Such extremes could also cause physical damage to the engine turbine blades. Therefore total water content in a unit volume of air in addition to precipitation rate is required and provided.

Another family of problems involves triggering the impact fuses of artillery shells and aircraft bombs; still another, erosion of supersonic aircraft radomes and leading edges; finally, ablation of re-entry vehicles.

Guidance from the Office of the Assistant Secretary of Defense (JCS 1969) indicated that military equipment intended for worldwide operations should be designed so that inoperability due to precipitation extremes occurs only 0.5 percent of the time during the worst month in the severest general rainy areas, the very extensive moist tropics.

Table 55. Highest Recorded 1-Km Wind Shear Extremes for the Worldwide Air Environment — 1 to 30 Km

Altitude Above Sea Level			
Altitude (Km)	Location (Area)	Value (mps)	Month
1	Eastern United States	42	Jan
2	Southern Japan	32	Jan
4	Ryukyu Islands	45	Jan
6	Iceland	49	Feb
8	Southern Japan	44	Jan
10	Northern Japan	57	Jan
12	Southern Japan	65	Jan
14	Southern Japan	53	Jan
16	Southern Japan	57	Jan
18	Southern Japan	70	Jan
20	Eastern United States	61	Jan
22	Eastern United States	49	Jan
24	Eastern United States	46	Jan
26	Eastern United States	44	Jan
28	Iceland	42	Jan
30	Eastern United States	38	Jan

Pressure Altitude			
Height (Km)	Location (Area)	Value (mps)	Month
1	Eastern United States	42	Jan
2	Eastern United States	34	Jan
4	Ryukyu Islands	44	Jan
6	Iceland	49	Feb
8	Southern Japan	44	Jan
10	Northern Japan	57	Jan
12	Southern Japan	65	Jan
14	Southern Japan	52	Jan
16	Southern Japan	59	Jan
18	Southern Japan	71	Jan
20	Eastern United States	62	Jan
22	Eastern United States	49	Jan
24	Eastern United States	47	Jan
26	Eastern United States	41	Jan
28	Iceland	40	Jan
30	Eastern United States	37	Jan

Table 56. One Percent 1-Km Wind Shear Extremes for the Worldwide Air Environment – 1 to 30 Km

Altitude Above Sea Level			
Altitude (km)	Location (Area)	Value (mps)	Month
1	Eastern United States	25	Jan
2	Southern Japan	23	Jan
4	Ryukyu Islands	24	Jan
6	Ryukyu Islands	29	Jan
8	Southern Japan	32	Jan
10	Eastern United States	32	Jan
12	Eastern United States	33	Jan
14	Southern Japan	50	Jan
16	Southern Japan	56	Jan
18	Southern Japan	45	Jan
20	Eastern United States	41	Jan
22	Eastern United States	37	Jan
24	Eastern United States	33	Jan
26	Eastern United States	34	Jan
28	Iceland	41	Jan
30	Eastern United States	30	Jan

Pressure Altitude			
Height (km)	Location (Area)	Value (mps)	Month
1	Iceland	26	Jan
2	Southern Japan	22	Jan
4	Ryukyu Islands	23	Jan
6	Ryukyu Islands	30	Jan
8	Southern Japan	32	Jan
10	Eastern United States	31	Jan
12	Eastern United States	32	Jan
14	Southern Japan	50	Jan
16	Southern Japan	58	Jan
18	Southern Japan	46	Jan
20	Eastern United States	42	Jan
22	Eastern United States	37	Jan
24	Eastern United States	33	Jan
26	Eastern United States	33	Feb
28	Iceland	33	Jan
30	Iceland	30	Jan

Table 57. Five Percent 1-Km Wind Shear Extremes for the Worldwide Air Environment – 1 to 30 Km

Altitude Above Sea Level			
Altitude (km)	Location (Area)	Value (mps)	Month
1	Eastern United States	19	Jan
2	Southern Japan	16	Jan
4	Southern Japan	18	Jan
6	Ryukyu Islands	22	Jan
8	Eastern United States	24	Feb
10	Eastern United States	20	Jan
12	Southern Japan	22	Jan
14	Southern Japan	29	Jan
16	Southern Japan	28	Jan
18	Southern Japan	24	Jan
20	Southern Japan	20	Jan
22	Northern Japan	20	Jan
24	Iceland	17	Jan
26	Iceland	18	Jan
28	Iceland	28	Feb
30	Eastern United States	20	Jan

Pressure Altitude			
Height (km)	Location (Area)	Value (mps)	Month
1	Eastern United States	19	Jan
2	Southern Japan	16	Jan
4	Southern Japan	18	Jan
6	Ryukyu Islands	23	Jan
8	Eastern United States	24	Feb
10	Eastern United States	19	Jan
12	Southern Japan	21	Jan
14	Southern Japan	29	Jan
16	Southern Japan	30	Jan
18	Southern Japan	24	Jan
20	Southern Japan	20	Jan
22	Northern Japan	20	Jan
24	Iceland	17	Jan
26	Iceland	20	Feb
28	Iceland	26	Feb
30	Eastern United States	20	Jan

Table 58. Ten Percent 1-Km Wind Shear Extremes for the Worldwide Air Environment – 1 to 50 Km

Altitude Above Sea Level			
Altitude (km)	Location (Area)	Value (mps)	Month
1	Eastern United States	17	Jan
2	Eastern United States	15	Feb
4	Southern Japan	15	Jan
6	Ryukyu Islands	18	Jan
8	Southern Japan	20	Jan
10	Southern Japan	18	Jan
12	Southern Japan	17	Jan
14	Southern Japan	20	Jan
16	Southern Japan	21	Jan
18	Southern Japan	17	Jan
20	Southern Japan	14	Jan
22	Northern Japan	15	Jan
24	Iceland	13	Jan
26	Iceland	15	Jan
28	Iceland	17	Jan
30	Iceland	16	Jan

Pressure Altitude			
Height (km)	Location (Area)	Value (mps)	Month
1	Eastern United States	17	Jan
2	Eastern United States	15	Feb
4	Southern Japan	15	Jan
6	Ryukyu Islands	19	Jan
8	Southern Japan	20	Jan
10	Southern Japan	17	Jan
12	Southern Japan	17	Jan
14	Southern Japan	19	Jan
16	Southern Japan	22	Jan
18	Southern Japan	17	Jan
20	Southern Japan	14	Jan
22	Northern Japan	15	Jan
24	Iceland	14	Jan
26	Iceland	15	Jan
28	Iceland	15	Jan
30	Iceland	16	Jan

Table 59. Twenty Percent 1-Km Wind Shear Extremes for the Worldwide Air Environment — 1 to 30 Km

Altitude Above Sea Level			
Altitude (km)	Location (Area)	Value (mps)	Month
1	Eastern United States	13	Jan
2	Eastern United States	12	Feb
4	Southern Japan	13	Jan
6	Ryukyu Islands	14	Jan
8	Southern Japan	17	Jan
10	Southern Japan	17	Jan
12	Southern Japan	14	Jan
14	Southern Japan	18	Jan
16	Southern Japan	19	Jan
18	Southern Japan	14	Jan
20	Southern Japan	12	Jan
22	Northern Japan	13	Jan
24	Iceland	10	Jan
26	Iceland	10	Jan
28	Iceland	12	Jan
30	Iceland	13	Jan

Pressure Altitude			
Height (km)	Location (Area)	Value (mps)	Month
1	Eastern United States	13	Jan
2	Eastern United States	12	Feb
4	Southern Japan	13	Jan
6	Ryukyu Islands	14	Jan
8	Southern Japan	17	Jan
10	Southern Japan	16	Jan
12	Southern Japan	14	Jan
14	Southern Japan	18	Jan
16	Southern Japan	19	Jan
18	Southern Japan	14	Jan
20	Southern Japan	12	Jan
22	Northern Japan	13	Jan
24	Iceland	11	Jan
26	Iceland	10	Jan
28	Iceland	10	Jan
30	Iceland	13	Jan

Table 60. Extremes of Precipitation Rate and Water Concentrations for the Worldwide Air Environment

Altitude (km)	Ratios prec	Ratios cld	0.5% Worst Month Tropics rate $\left(\frac{mm}{min}\right)$	0.5% Worst Month Tropics water prec $\left(\frac{g}{m^3}\right)$	0.5% Worst Month Tropics water cld $\left(\frac{g}{m^3}\right)$	0.1% Worst Month Tropics rate $\left(\frac{mm}{min}\right)$	0.1% Worst Month Tropics water prec $\left(\frac{g}{m^3}\right)$	0.1% Worst Month Tropics water cld $\left(\frac{g}{m^3}\right)$	42-Minute Record rate $\left(\frac{mm}{min}\right)$	42-Minute Record water prec $\left(\frac{g}{m^3}\right)$	42-Minute Record water cld $\left(\frac{g}{m^3}\right)$	1-Minute Record rate $\left(\frac{mm}{min}\right)$	1-Minute Record water prec $\left(\frac{g}{m^3}\right)$	1-Minute Record water cld $\left(\frac{g}{m^3}\right)$
Surface	1.00	0	0.80	2.22	0	3.13	8.34	0	7.26	18.88	0	31.2	77.65	0
1.5	1.12	0.83	0.90	2.49	2.07	3.50	9.30	8.12	8.15	21.12	8.12	34.9	86.57	8.12
3.0	1.24	0.92	0.99	2.73	2.30	3.88	10.28	9.00	9.02	23.30	9.00	38.7	95.70	9.00
4.5	1.35	1.00	1.08	2.97	2.50	4.23	11.18	9.78	9.82	25.30	9.78	42.1	103.80	9.78
6.0	1.35	1.00	1.08	2.97	2.50	4.23	11.18	9.78	9.82	25.30	9.78	42.1	103.80	9.78
9.0	0.75	0.56	0.60	1.68	1.44	2.35	6.32	5.53	5.44	14.27	5.53	23.5	58.98	5.53
12.0	0.44	0.32	0.35	0.97	0.81	1.38	3.77	3.18	3.19	8.50	3.18	13.8	35.20	3.18
15.0	0.19	0.14	0.15	0.43	0.35	0.59	1.65	1.38	1.38	3.77	1.38	5.94	15.54	1.38
18.0	0.03	0.02	0.02	0.06	0.05	0.09	0.27	0.21	0.22	0.66	0.21	0.94	2.59	0.21

Note:
1. Intensities are 1-min averages; 10-sec extremes will be 110% of these values.
2. Cloud density is not increased as rain intensity increases beyond the 0.1% model.
3. All liquid below 4.5 km; mostly liquid at 4.5 to 6 km becoming increasingly ice up to 10 km; nearly all ice above 10 km.
4. For total water concentration add precipitation and cloud water.
5. Cloud, particles less than 100 μ in diameter.

1.4.1.1 Highest Recorded

Since only sporadic research data are available for rainfall and the associated liquid water concentration at altitude, there is no inventory of data from which one can select record extremes. However, such extremes have a direct relationship with extremes at the surface since these surface extremes are produced in thunderstorms which are most intense at altitude just above the freezing level, about 4.5 km. Sissenwine[71] indicates that a value of 135 percent of the surface record intensity (31.2 mm/min) at 4.5 to 6 km is typical during such extremes. Therefore, intensities of more than 42 mm/min in which the total rain and cloud liquid water concentration is more than 100 g/m^3, at 4.5 to 6 km, can be considered the associated record at altitude when the record surface intensity for 1 min, 31.2 mm/min was observed.

The actual measured liquid water concentration extreme[71] at altitude was 44 g/m^3 ingested into the compression chamber of an F-100 aircraft at 29,000 ft. If this were all precipitation it would provide precipitation intensity of 17.4 mm/min at 29,000 ft.

1.4.1.2 Operations

All military equipment designed for worldwide operations should be able to operate in the conditions at altitude indicated by the "0.5% Worst Month Tropics" column in Table 60. Such conditions will be encountered with about this probability over a vast area of the earth which can be considered the rainy humid tropics. If inoperability of the equipment when encountering precipitation aloft will endanger human life, then the value provided under the "1-minute Record" column should be used as a goal. The "0.1% Worst Month Tropics" column should serve only as an interim goal as a last resort, since it implies one encounter over a single location in 1000 hr of flying in the rainy tropics. Therefore, the likelihood of encounter by some of many aircraft in a tropical combat situation would be very high. The values for "42-Minute Record" in Table 60 would be a more acceptable compromise. No probability can be attached to it but it is of about the same intensity as values estimated by Briggs[72] with a probability of one encounter in 10^5 hr of year-round flying in the rainy tropics, roughly once in ten years.

For MIL-STD-210B, the values in Table 60 can be linearly interpolated to give values at the same height intervals used by Richard and Snelling[52] for the other elements in the chapter.

72. Briggs, J. (1972) Probabilities of aircraft encounter with heavy rain, Met. Mag. 101(No. 1194):8-13.

1.4.1.3 Drop Sizes[36]

Drop sizes for the precipitation extremes given in Table 60 were provided by Tattelman and Sissenwine[36] as previously discussed in Section II.4.1.2.2. These sizes are given in Table 61.

1.4.1.4 Associated Temperatures

Temperatures associated with precipitation rates given in Table 60 were obtained from U.S. Standard Atmosphere Supplements[5] at 15° latitude since intense precipitation rates occur in the tropics. These are listed in Table 62.

1.4.1.5 Horizontal Extent

Information on the horizontal extent of intense precipitation rates was provided by Sims and Jones.[73] The information was derived from mid-latitude squall line conditions. Under such conditions when the point surface (0 km) precipitation rate is 0.80 mm/min, the line average surface rate is 0.50 mm/min for a 5-mi distance, 0.36 mm/min for 10 mi, 0.30 mm/min for 14 mi, 0.27 mm/min for 20 mi, 0.25 mm/min for 30 mi, and 0.24 mm/min for 40 mi. No data on the horizontal extent of precipitation is available beyond 40 mi nor for altitudes above the surface.

1.4.2 WATER CONCENTRATION IN PRECIPITATION

1.4.2.1 Highest Recorded

See Table 60.

1.4.2.2 Operations

See Table 60.

1.4.3 HAIL SIZE[47]

Section II.4.4 which presents hail size extremes for surface operations and withstanding, also discusses characteristics of hail and hailstorms germane to this section.

Information in Section II.4.4 was prepared by Gringorten.[47] In the same paper, extremes of hail size for operations aloft are presented. Extremes were determined for two types of equipment—that which traverses horizontal segments of the atmosphere and equipment which essentially rises vertically.

Having determined extremes of hail size at the surface, Gringorten was faced with three problems in attempting to describe extremes of hail size aloft: (1) Do the conditional probabilities of surface hail sizes in Section II.4.4 (see Figure 16) apply aloft; (2) do the probabilities of encountering hail aloft differ from those at

73. Sims, A.L., and Jones, D.M.A. (1973) Climatology of Instantaneous Precipitation Rates, AFCRL-TR-73-0171, 75 p.

Table 61. Drop Sizes Associated with Precipitation Rate Extremes for the Worldwide Air Environment

(a) Number of Drops (Liquid or Equivalent Liquid) per m^3 for the 1-min World-Record Rainfall

Altitude (km)	Rainfall Intensity (mm/min)	Median Diameter (mm)	Diameter (mm)					
			0.5-1.4	1.5-2.4	2.5-3.4	3.5-4.4	4.5-5.4	5.5-6.4
0	31	2.2	158,624	29,915	5642	1064	201	38
1	34	2.2	174,297	32,870	6199	1169	220	42
2	36	2.2	184,761	34,844	6571	1239	234	44
4	41	2.2	210,970	39,787	7503	1415	267	50
6	42	2.2	216,220	40,777	7690	1450	274	52
8	30	2.2	153,407	28,930	5456	1029	194	37
10	20	2.1	93,699	16,321	2843	495	86	15
12	14	2.1	65,123	11,344	1976	344	60	10
14	9	2.0	38,024	6,069	969	155	25	4
16	4	1.9	15,097	2,188	317	46	7	1
18	1	1.8	3,298	429	56	7	1	< 1
20	0	-	-	-	-	-	-	-

(b) Number of Drops (Liquid or Equivalent Liquid) per m^3 Equalled or Exceeded With 0.1 Percent Probability, Worst Month, Wet Tropics

Altitude (km)	Rainfall Intensity (mm/min)	Median Diameter (mm)	Diameter (mm)					
			0.5-1.4	1.5-2.4	2.5-3.4	3.5-4.4	4.5-5.4	5.5-6.4
0	3.13	1.9	11,755	1,704	247	36	5	1
1	3.38	1.9	12,714	1,843	267	39	6	1
2	3.63	1.9	13,674	1,982	287	42	6	1
4	4.11	1.9	15,521	2,249	326	47	7	1
6	4.23	1.9	15,983	2,316	336	49	7	1
8	2.97	1.9	11,143	1,615	234	34	5	1
10	2.03	1.9	7,559	1,095	159	23	3	< 1
12	1.38	1.8	4,530	596	78	10	1	< 1
14	0.85	1.8	2,794	364	47	6	1	< 1
16	0.43	1.7	1,237	143	16	2	< 1	< 1
18	0.09	1.6	219	22	2	< 1	< 1	< 1
20	0	-	-	-	-	-	-	-

(c) Number of Drops (Liquid or Equivalent Liquid) per m^3 Equalled or Exceeded With 0.5 Percent Probability, Worst Month, Wet Tropics

Altitude (km)	Rainfall Intensity (mm/min)	Median Diameter (mm)	Diameter (mm)					
			0.5-1.4	1.5-2.4	2.5-3.4	3.5-4.4	4.5-5.4	5.5-6.4
0	0.80	1.8	2626	342	45	6	1	< 1
1	0.87	1.8	2861	372	48	6	1	< 1
2	0.93	1.8	3062	399	52	7	1	< 1
4	1.0	1.8	3298	429	56	7	1	< 1
6	1.1	1.8	3634	473	62	8	1	< 1
8	0.77	1.8	2526	329	43	6	1	< 1
10	0.51	1.8	1659	216	28	4	< 1	< 1
12	0.35	1.7	1002	116	13	2	< 1	< 1
14	0.22	1.7	624	72	8	1	< 1	< 1
16	0.11	1.6	269	27	3	< 1	< 1	< 1
18	0.02	1.5	41	4	< 1	< 1	< 1	< 1
20	0	-	-	-	-	-	-	-

Table 62. Temperatures Associated With Precipitation Rate Extremes for the Worldwide Air Environment

Altitude (km)	Temperature (°C)
0	29
1	23
2	16
4	4
6	-9
8	-23
10	-36
12	-50
14	-63
16	-76
18	-74
20	-66

the surface; and (3) how can probabilities of encountering hail along various line segments be determined from single-point probabilities?

To answer the first problem, Gringorten studied the problem of hail melting during fall. He found that the conditional probability distribution of hailstone diameters aloft must be practically the same up to the freezing level, 13,000 to 14,000 ft, as at the ground level in the area of worst hailstorms for hailstones of significant diameters.

In answering the second question regarding hail probabilities aloft, Gringorten used information from the U.S. Weather Bureau 1947-1948 Thunderstorm Project which indicated that, for the Ohio and Florida areas, hail was encountered at approximately 10, 15, 20, and 25,000 ft in thunderstorms about 9, 7, 5, and 3 times as often as it was at 5000 ft. Above 30,000 ft hail has been encountered infrequently but cannot be discounted. Five-in. hailstones have been reported at 29,500 ft, 4-in. hailstones at 31,000 ft, and 3-in. hailstones at 37,000 ft.

In the absence of more objective data, Gringorten used inference to determine the frequency of hail aloft as a function of height. He reasoned that hailstones must form, and grow in size, above the freezing level in the atmosphere. Once formed, the hailstones will fall or be buffeted vertically up and down, or become suspended at a "balance" level. This should be a level of high concentration and therefore a level of high probability of hail occurrence. Balance levels are near, but below, the level of updraft maximum which places them significantly above the freezing

level. Gringorten quotes one author depicting balance levels at roughly 20,000 ft, the same height described by another author as having the greatest concentration of large hail in several analyzed thunderstorms. With this meager information on the relative frequencies of hail encounter aloft and the height of the balance level, and without trying to exhaustively resolve this problem, Gringorten assumed that the probability of encountering hail is uniformly the same at any level from 10,000 ft to 20,000 ft, and that any level in this interval can become a level of hail concentration. Concomitantly he assumed that the probability of hail encounter decreased downward from 10,000 ft to 5,000 ft and decreases upward from 20,000 ft to 45,000 ft.

Since hailstones do not form or grow at the 5000 ft level but simply fall through that level, and since hailstones do not appreciably melt from that level to the surface, the probability of hail encounter at levels at (and below) 5000 ft was assumed to be the same as that found at the surface, 0.000448, (see Section II.4.4).

Averaging the reports of hail encounter at 10, 15, and 20,000 ft during the 1947-1948 Thunderstorm Project, Gringorten estimated that any level between 10 and 20,000 ft experiences 7 times more hail occurrences than the 5000 ft level, 0.00314. At 25,000 ft, again from the Thunderstorm Project, Gringorten accepted the probability as 3 times greater than at 5000 ft, 0.00134.

Above 25,000 ft, the probability of hailstone encounter must diminish steadily. Arbitrarily Gringorten assumed that the probability decreases linearly to a probability of 0 at 45,000 ft. A summary of the probability of a hailstorm for various levels aloft is given in Table 63. Between 5 and 10,000 ft, 20 and 25,000 ft, 25 and 45,000 ft, the probability is assumed to change linearly with altitude.

Table 63. Estimates of the Probability of Encountering Hail of Any Size at a Single-Point Location by Altitude (Over the Center of U.S. Hail Activi' ' in the Most Severe Month)

Altitude	Probability	% Risk
Ground Level	0.000448	0.0448
5,000 ft	0.000448	0.0448
10,000 ft	0.00314	0.314
15,000 ft	0.00314	0.314
20.000 ft	0.00314	0.314
25,000 ft	0.00134	0.134
30,000 ft	0.00100	0.100
35,000 ft	0.00067	0.067
40,000 ft	0.00034	0.034
45,000 ft	0.0000	0.000

In answer to the last question of determining hail encounter probabilities along a horizontal line segment from single-point probabilities, Gringorten employed a model-undergoing development by him which related various areal and lineal probabilities of an event to its single-point probability. The model is based upon the assumption that the correlation between two normalized variables decreases with the square of the distance between them.

Using this model with previously determined measurements of areal versus point frequencies of hail occurrences, Gringorten calculated probabilities of hail encounter for 100- and 200-mi representative traverses across the area having the highest frequency of hail during the most extreme month. These probabilities depicted in Table 64 apply in the vicinity of the area where the single-point probabilities are as given in Table 63.

Table 64. Model Estimates of the Probability of Encountering Hail of Any Size on 100- and 200-Mile Routes Aloft

Altitude	Probability (% Risk)	
	100-mi Route	200-mi Route
Surface	0.010 (1.0%)	0.021 (2.1%)
5,000 ft	0.010 (1.0%)	0.021 (2.1%)
10,000 ft	0.50 (5.0%)	0.095 (9.5%)
20,000 ft	0.50 (5.0%)	0.095 (9.5%)
25,000 ft	0.023 (2.3%)	0.044 (4.4%)
30,000 ft	0.019 (1.9%)	0.037 (3.7%)
35,000 ft	0.0145 (1.45%)	0.030 (3.0%)
40,000 ft	0.0090 (0.90%)	0.019 (1.9%)
45,000 ft	0 (0%)	0 (0%)

1.4.3.1 Largest Recorded

Since, as pointed out above, large hailstones do not undergo significant melting when falling to the surface, the surface value quoted in Section II.4.4.1 may be used to represent "largest recorded" hailstones aloft. The largest hailstone on record measured 5.6 in. in diam.

1.4.3.2 Operations

1.4.3.2.1 SINGLE-POINT VERTICAL EXTREMES

As pointed out above, the conditional probability distribution of hailstone size at ground level provided in Section II.4.4 can be used as the conditional probability

distribution for upper levels. By multiplying the probability of encountering a hailstorm at a given altitude (Table 63) by the conditional probability of exceeding a given size (Figure 16), the probability of encountering hailstones equal to or greater than the given size for that altitude is obtained. These are given in Table 65.

Table 65. Estimated Probabilities of Encountering Hailstones by Size at a Single-Point Aloft

Hail Diam (in.) (h)	Level (thousands of feet)					
	SFC-5	10-20	25	30	35	40	45
Any size	0.000448	0.00314	0.00134	0.0010	0.00067	0.00034	0
≥ 0.25	0.000354	0.00250	0.00106	0.0008	0.00053	0.00027	0
≥ 0.5	0.000161	0.00113	0.00048	0.00036	0.00024	0.00017	0
≥ 1.0	0.0000314	0.00022	0.00009	0.00007	0.00005	0.00003	0
≥ 2.0	0.00000851	0.00006	0.00002	0.00002	0.00001	0.000005	0
≥ 3.0	0.00000170	0.00001	0.00001	0.	0.	0.	0

Note: For percent risk, multiply each probability value by 100.

The greater frequency of large stones aloft, compared with ground-level frequency, is attributed to the greater frequency of hail of any kind aloft, especially at the "balance" level somewhere between 10 and 20,000 ft. These probabilities are sufficiently low that there is no need to specify a hail size extreme for vertically-rising equipment when failure due to hail would not endanger human life. For equipment whose failure due to hail would result in danger to human life, the record hailstone size, 5.6 in., should be considered as the criteria if accommodation of such an extreme is at all possible in the design of a particular item.

1.4.3.2.2 HORIZONTAL TRAVERSE EXTREMES

As in Section 1.4.3.2.1 above, the conditional probabilities of hailstone sizes given in Figure 16 are multiplied by the probabilities of encountering hail of any size for various altitudes/routes given in Table 64 to obtain the probability of encountering various size hail on 100- and 200-mi routes aloft. These probabilities are given in Table 66.

These probabilities/percent risks are considerably higher than the single-point probabilities given in Table 65. In fact, the percent risks exceed 1 percent at a number of levels for a number of sizes. Taking a 200-mi traverse to represent the most extreme conditions that would be encountered, one obtains values in Table 67

Table 66. Estimated Probabilities of Encountering Hailstones by Size on 100- and 200-Mile Routes Aloft

Hail Diam (in., h)	Level (thousands of feet)						
	SFC-50	10-20	25	30	35	40	45
Any Size							
100-mi	0.010	0.050	0.023	0.019	0.0145	0.0090	0
200-mi	0.021	0.095	0.044	0.037	0.030	0.019	0
≥ 0.25							
100-mi	0.0079	0.0395	0.0182	0.0151	0.0115	0.00711	0
200-mi	0.0166	0.0751	0.0248	0.0292	0.0237	0.0150	0
≥ 0.50							
100-mi	0.0036	0.0180	0.00828	0.00684	0.00522	0.00324	0
200-mi	0.0076	0.0342	0.0158	0.0133	0.0108	0.00684	0
≥ 1.0							
100-mi	0.00070	0.0035	0.00161	0.00133	0.00102	0.000630	0
200-mi	0.00147	0.00665	0.00308	0.00259	0.00210	0.00133	0
≥ 2.0							
100-mi	0.00019	0.00096	0.000437	0.000361	0.000276	0.000171	0
200-mi	0.00040	0.0018[illegible]	0.000836	0.000703	0.000570	0.000361	0
≥ 3.0							
100-mi	0.000038	0.000190	0.0000874	0.0000722	0.0000551	0.0000342	0
200-mi	0.000080	0.000361	0.000187	0.000141	0.000114	0.0000722	0

Note: For percent risk, multiply each probability by 100.

Table 67. Hail Sizes Attained or Exceeded with 1 Percent Probability on 200 NM Horizontal Traverse Aloft

Altitude at Which Equipment Will Be Used	1% Hail Size
SFC – 5000 ft	0.43 in.
10 - 20,000 ft	0.81 in.
25,000 ft	0.60 in.
30,000 ft	0.56 in.
35,000 ft	0.51 in.
40,000 ft	0.40 in.
45,000 ft	0 in.

by interpolation from Table 66. These are hail sizes for the usual 1 percent operational risk in the most severe area during the most extreme month.

When failure of equipment, especially aircraft and aircraft components, due to hail would result in danger to human life, the record hailstone size 5.5 in. should

be considered as the design criteria goal if such an extreme is at all possible in the design of a particular item. When design for this record size is not feasible, the 0.1 percent extreme is recommended for use. Table 68 gives the recommended 0.1 percent hail size extremes for the various altitudes aloft.

Table 68. Hail Sizes Attained or Exceeded with 0.1 Percent Probability on 200 NM Traverses Aloft

Altitude at Which Equipment Will Be Used	0.1% Hail Size
SFC – 5000 ft	1.2 in.
10 - 20,000 ft	2.4 in.
25,000 ft	1.9 in.
30,000 ft	1.7 in.
35,000 ft	1.5 in.
40,000 ft	1.1 in.
45,000 ft	0 in.

For MIL-STD-210B, the values in Tables 67 and 68 can be linearly interpolated to give values at the same height intervals by Richard and Snelling[52] for the other elements in this chapter.

1.5 Pressure

From data sources available at the National Weather Data Center, ETAC determined that the values of pressure in the Southern Hemisphere were in general less extreme than those in the Northern Hemisphere. Therefore, all statistics selected were from sites in the Northern Hemisphere.

1.5.1 HIGH PRESSURE

Table 69 lists extremes of high pressure. These extremes are found in the mid-latitudes at the lower altitudes. Generally, with increasing height, the extremes of high pressure are found further north. The exception is at the 1-km level where the extreme of high pressure is located at about 80°N, the result of a cold, shallow, high-pressure dome dominating the weather regime in the area. Except for the 1 km highest recorded and 1 percent extreme, which occur in January, all other high pressure extremes occur in July, opposite to their occurrence at the surface.

Table 69. High Pressure Extremes for the Worldwide Air Environment – 1 to 30 km

Altitude (km)	Highest Recorded Location (Area)	Value (mbar)	Mo.	1% Probable Location (Area)	Value (mbar)	Mo.	5% Probable Location (Area)	Value (mbar)	Mo.
1	NWT Canada	930	Jan	NWT Canada	920	Jan	Mid-North Atlantic	918	Jul
2	Azores	821	Jan	Azores	817	Jul	Azores	816	Jul
4	Azores	643	Jul	Azores	642	Jul	Mid-North Atlantic	641	Jul
6	Azores	501	Jul	Azores	499	Jul	Azores	497	Jul
8	Saudi Arabia	385	Jul	Saudi Arabia	384	Jul	Southern India	383	Jul
10	Southern India	294	Jul	Southern India	293	Jul	Southern India	292	Jul
12	Eastern India	226	Jul	Eastern India	226	Jul	Eastern India	224	Jul
14	Eastern India	168	Jul	Eastern India	167	Jul	Eastern India	166	Jul
16	Eastern India	123	Jul	Eastern India	123	Jul	Eastern India	122	Jul
18	Eastern India	88	Jul	Eastern India	88	Jul	Eastern India	87	Jul
20	NWT Canada	65	Jul	NWT Canada	65	Jul	NWT Canada	74	Jul
22	NWT Canada	45	Jul	NWT Canada	45	Jul	NWT Canada	44	Jul
24	NWT Canada	35	Jul	NWT Canada	34	Jul	NWT Canada	33	Jul
26	NWT Canada	26	Jul	NWT Canada	25	Jul	NWT Canada	25	Jul
28	NWT Canada	20	Jul	NWT Canada	19	Jul	NWT Canada	19	Jul
30	NWT Canada	15	Jul	NWT Canada	15	Jul	NWT Canada	14	Jul

Height (km)	10% Probable Location (Area)	Value (mbar)	Mo.	20% Probable Location (Area)	Value (mbar)	Mo.
1	Mid-North Atlantic	917	Jul	Mid-North Atlantic	916	Jul
2	Azores	815	Jul	Azores	814	Jul
4	Mid-North Atlantic	640	Jul	Mid-North Atlantic	639	Jul
6	Mid-North Atlantic	496	Jul	Mid-North Atlantic	495	Jul
8	Southern India	382	Jul	Southern India	381	Jul
10	Saudi Arabia	291	Jul	Saudi Arabia	290	Jul
12	Eastern India	223	Jul	Eastern India	222	Jul
14	Eastern India	165	Jul	Eastern India	164	Jul
16	Eastern India	121	Jul	Eastern India	120	Jul
18	Eastern India	86	Jul	Eastern India	85	Jul
20	NWT Canada	63	Jul	NWT Canada	62	Jul
22	NWT Canada	44	Jul	NWT Canada	43	Jul
24	NWT Canada	32	Jul	NWT Canada	32	Jul
26	NWT Canada	24	Jul	NWT Canada	24	Jul
28	NWT Canada	18	Jul	NWT Canada	18	Jul
30	NWT Canada	14	Jul	NWT Canada	13	Jul

1.5.1.1 Highest Recorded

Highest recorded values for each level are given in Table 69.

1.5.1.2 Operations

The 1, 5, 10, and 20 percent high pressure extremes for each level are provided in Table 69.

1.5.2 LOW PRESSURE

Table 70 presents extremes of low pressure. All extremes are found in January and generally between 70° and 80°N.

1.5.2.1 Lowest Recorded

Lowest recorded values for each level are provided in Table 70.

1.5.2.2 Operations

The 1, 5, 10, and 20 percent low pressure extremes for each level are given in Table 70.

1.6 Density

Fourteen stations were selected for investigation of density extremes. Since the global density distribution has a poleward gradient, the stations were selected so as to range from the equator to the poles.

In computing the density statistic from the sounding data, the following equation was used:

$$\rho = \frac{P}{RT}\left(1 - 0.379\,\frac{e}{P}\right)$$

where

ρ = density in kg/m^3
P = pressure in mbar
R = the gas constant, 2.87053
T = temperature in °K
e = vapor pressure in mbar.

Some problems were incurred in identifying the extreme values in the layers above 20 km. These problems involved lack of data, sample size, period of record, and method of computation. In selecting the value to be used, the tendency was to give preference to the value from the larger sample size and the longer period of record. In instances of little or no data extremes of density at pressure-altitudes, especially for low density extremes, the statistics were determined by

Table 70. Low Pressure Extremes for the Worldwide Air Environment – 1 to 30 km

Altitude (km)	Lowest Recorded Location (Area)	Lowest Recorded Value (mbar)	Lowest Recorded Mo.	1% Probable Location (Area)	1% Probable Value (mbar)	1% Probable Mo.	5% Probable Location (Area)	5% Probable Value (mbar)	5% Probable Mo.
1	Greenland	842	Jan	Greenland	847	Jan	Greenland	856	Jan
2	NWT Canada	736	Jan	NWT Canada	742	Jan	NWT Canada	748	Jan
4	NWT Canada	548	Jan	NWT Canada	550	Jan	NWT Canada	558	Jan
6	NWT Canada	406	Jan	NWT Canada	408	Jan	NWT Canada	413	Jan
8	NWT Canada	236	Jan	NWT Canada	299	Jan	NWT Canada	303	Jan
10	NWT Canada	215	Jan	NWT Canada	216	Jan	NWT Canada	221	Jan
12	NWT Canada	154	Jan	NWT Canada	157	Jan	NWT Canada	158	Jan
14	NWT Canada	111	Jan	NWT Canada	111	Jan	NWT Canada	113	Jan
16	NWT Canada	79	Jan	NWT Canada	79	Jan	NWT Canada	80	Jan
18	NWT Canada	56	Jan	NWT Canada	56	Jan	NWT Canada	57	Jan
20	NWT Canada	40	Jan	NWT Canada	41	Jan	NWT Canada	42	Jan
22	NWT Canada	28	Jan	NWT Canada	29	Jan	NWT Canada	30	Jan
24	NWT Canada	20	Jan	NWT Canada	21	Jan	NWT Canada	24	Jan
26	NWT Canada	14	Jan	NWT Canada	15	Jan	NWT Canada	18	Jan
28	NWT Canada	10	Jan	NWT Canada	11	Jan	NWT Canada	13	Jan
30	Greenland	7	Jan	Greenland	9	Jan	NWT Canada	10	Jan

Height (km)	10% Probable Location (Area)	10% Probable Value (mbar)	10% Probable Mo.	20% Probable Location (Area)	20% Probable Value (mbar)	20% Probable Mo.
1	Greenland	861	Jan	Greenland	868	Jan
2	NWT Canada	752	Jan	NWT Canada	757	Jan
4	NWT Canada	565	Jan	NWT Canada	569	Jan
6	NWT Canada	418	Jan	NWT Canada	422	Jan
8	NWT Canada	306	Jan	NWT Canada	309	Jan
10	NWT Canada	223	Jan	NWT Canada	225	Jan
12	NWT Canada	160	Jan	NWT Canada	162	Jan
14	NWT Canada	115	Jan	NWT Canada	117	Jan
16	NWT Canada	82	Jan	NWT Canada	84	Jan
18	NWT Canada	58	Jan	NWT Canada	59	Jan
20	NWT Canada	43	Jan	NWT Canada	45	Jan
22	NWT Canada	31	Jan	NWT Canada	32	Jan
24	NWT Canada	27	Jan	NWT Canada	28	Jan
26	NWT Canada	20	Jan	NWT Canada	21	Jan
28	NWT Canada	15	Jan	NWT Canada	16	Jan
30	NWT Canada	11	Jan	NWT Canada	12	Jan

comparison with sites for which both geopotential height and pressure-altitude statistics were available. There is little variation from station to station in the polar-region values. In the vicinity of the equator, the winter-season values are very similar to the summer-season values.

There appears to be no set pattern as to the magnitude or the direction of the difference between the density at a geopotential altitude surface and the density value at a corresponding pressure-altitude surface.

In the following sections, the mean, maximum, and minimum temperatures associated with the density extremes at heights above sea level are also given.

1.6.1 HIGH DENSITY

1.6.1.1 Highest Recorded

The highest recorded values for each level are shown in Table 71.

1.6.1.2 Operations

The 1, 5, 10, and 20 percent high density extremes are given in Tables 72, 73, 74, and 75 respectively.

1.6.2 LOW DENSITY

1.6.2.1 Lowest Recorded

The lowest recorded values for each level are shown in Table 76.

1.6.2.2 Operations

The 1, 5, 10, and 20 percent low density extremes at each level are given in Tables 77, 78, 79, and 80 respectively.

1.7 Ozone Concentration

This part on high ozone extremes up to 30 km was not prepared by ETAC, but is based on a background report by Borden[74] and interpretation of Borden's report by Kantor.[75]

From January 1963 through May 1969 inclusive, the AFCRL conducted an experimental program to measure the vertical distribution of atmospheric ozone. During the first 3 years, the observational network consisted of 12 stations in North America. The ozonesonde instrument used was the Regener chemiluminescent type. The data from this early network have been published in a series of reports.

74. Borden, T. R., Jr. (1970) Extreme Values of Ozone Observed in the AFCRL Ozonesonde Network, AFCRL-70-0072, ERP 312, 9 pp.

75. Kantor, A. J. (1972b) Ozone Density Envelopes up to 30 km for MIL-STD-210B, AFCRL (LKI) INAP No. 98.

Table 71. Highest Recorded Density Extremes for the Worldwide Air Environment – 1 to 30 km

Altitude (km)	Altitude Above Sea Level						Pressure Altitude		
	Density			Temperature (°C)			Density		
	Location (Area)	Value (kg/m^3)	Mo.	Mean	Maximum	Minimum	Location (Area)	Value (kg/m^3)	Mo.
1	NWT Canada	1.348	Mar	-43	-43	-43	NWT Canada	1.382	Jan
2	NWT Canada	1.173	Jan	-45	-45	-45	NWT Canada	1.223	Jan
4	NWT Canada	0.899	Jan	-5	-53	-53	NWT Canada	0.968	Jan
6	NWT Canada	0.701	Jan	-49	-49	-49	NWT Canada	0.771	Jan
8	New Zealand	0.552	Jul	-43	-43	-43	NWT Canada	0.588	Jan
10	Kenya	0.434	Jan	-59	-59	-59	NWT Canada	0.453	Jan
12	Kenya	0.344	Jan	-60	-60	-60	NWT Canada	0.343	Jan
14	Panama	0.267	Jul	-69	-66	-71	Kenya	0.259	Jan
16	Kenya	0.205	Jan	-75	-73	-76	Kenya	0.193	Jan
18	Kenya	0.150	Jan	-86	-86	-86	Kenya	0.141	Jan
20	Kenya	0.107	Jul	-76	-76	-76	NWT Canada	0.101	Jan
22	Kenya	0.073	Jul	-7[illegible]	-71	-71	NWT Canada	0.073	Jan
24	New Zealand	0.057	Jul	-59	-50	-65	NWT Canada	0.053	Jan
26	NWT Canada	0.043	Jul	-40	-40	-41	NWT Canada	0.041	Jan
28	NWT Canada	0.028	Jul	-38	-36	-41	NWT Canada	0.029	Jan
30	NWT Canada	0.021	Jul	-35	-34	-38	NWT Canada	0.0[illegible]2	Jan

Table 72. One Percent High Density Extremes for the Worldwide Air Environment – 1 to 30 km

Altitude (km)	Altitude Above Sea Level						Pressure Altitude		
	Density			Temperature (°C)			Density		
	Location (Area)	Value (kg/m³)	Mo.	Mean	Maximum	Minimum	Location (Area)	Value (kg/m³)	Mo.
1	NWT Canada	1.331	Feb	-37	-36	-38	NWT Canada	1.362	Jan
2	NWT Canada	1.15[illegible]	Feb	-39	-39	-39	NWT Canada	1.206	Jan
4	NWT Canada	0.892	Jan	-47	-44	-49	NWT Canada	0.952	Jan
6	NWT Canada	0.695	Jan	-44	-44	-45	NWT Canada	0.751	Jan
8	New Zealand	0.550	Jul	47	-47	-47	NWT Canada	0.58[illegible]	Jan
10	Eastern U.S.	0.433	Jan	-59	-59	-59	NWT Canada	0.451	Jan
12	Panama	0.340	Jul	-53	-53	-53	NWT Canada	0.339	Jan
14	Panama	0.267	Jul	-69	-66	-71	Kenya	0.250	Jan
16	Kenya	0.205	Jan	-74	-70	-78	Kenya	0.193	Jan
18	Kenya	0.149	Jan	-83	-80	-86	Kenya	0.141	Jan
20	Kenya	0.105	Jul	-76	-76	-76	NWT Canada	0.100	Jan
22	Kenya	0.073	Jul	-71	-71	-71	NWT Canada	0.073	Jan
24	New Zealand	0.057	Jul	-59	-50	-65	NWT Canada	0.053	Jan
26	NWT Canada	0.043	Jul	-40	-40	-41	NWT Canada	0.041	Jan
28	NWT Canada	0.028	Jul	-38	-36	-41	NWT Canada	0.029	Jan
30	NWT Canada	0.021	Jul	-35	-34	-38	NWT Canada	0.022	Jan

Table 73. Five Percent High Density Extremes for the Worldwide Air Environment – 1 to 30 km

Altitude (km)	Altitude Above Sea Level						Pressure Altitude		
	Density			Temperature (°C)			Density		
	Location (Area)	Value (kg/m³)	Mo.	Mean	Maximum	Minimum	Location (Area)	Value (kg/m³)	Mo.
1	NWT Canada	1.30[illegible]	Feb	-30	-30	-30	NWT Canada	1.315	Jan
2	NWT Canada	1.141	Jan	-34	-32	-37	NWT Canada	1.172	Jan
4	NWT Canada	0.882	Feb	-41	-41	-41	NWT Canada	0.930	Jan
6	NWT Canada	0.688	Mar	-45	-39	-52	NWT Canada	0.742	Jan
8	New Zealand	0.548	Jul	-45	-42	-51	NWT Canada	0.584	Jan
10	New Zealand	0.429	Jan	-46	-43	-50	NWT Canada	0.447	Jan
12	Panama	0.339	Jul	-54	-53	-54	NWT Canada	0.334	Jan
14	Panama	0.266	Jul	-69	-66	-71	Panama	0.246	Jul
16	Kenya	0.203	Jan	-74	-68	-77	Kenya	0.191	Jan
18	Kenya	0.14[illegible]	Jan	-89	-89	-89	Kenya	0.138	Jan
20	Kenya	0.105	Jul	-76	-76	-76	NWT Canada	0.069	Jan
22	Kenya	0.073	Jul	-71	-71	-71	NWT Canada	0.073	Jan
24	New Zealand	0.057	Jul	-59	-50	-65	NWT Canada	0.053	Jan
26	NWT Canada	0.04[illegible]	Jul	-40	-40	-41	NWT Canada	0.040	Jan
28	NWT Canada	0.028	Jul	-38	-36	-41	NWT Canada	0.029	Jan
30	NWT Canada	0.021	Jul	-35	-34	-38	NWT Canada	0.022	Jan

Table 74. Ten Percent High Density Extremes for the Worldwide Air Environment – 1 to 30 km

Altitude (km)	Altitude Above Sea Level						Pressure Altitude		
	Density			Temperature (°C)			Density		
	Location (Area)	Value (kg/m^3)	Mo.	Mean	Maximum	Minimum	Location (Area)	Value (kg/m^3)	Mo.
1	NWT Canada	1.293	Jan	-33	-27	-40	NWT Canada	1.307	Jan
2	NWT Canada	1.129	Jan	-31	-26	-34	NWT Canada	1.162	Jan
4	NWT Canada	0.876	Jan	-37	-32	-43	NWT Canada	0.921	Jan
6	NWT Canada	0.685	Mar	-48	-37	-53	NWT Canada	0.737	Jan
8	New Zealand	0.546	Jul	-46	-44	-50	NWT Canada	0.581	Jan
10	New Zealand	0.428	Jan	-44	-40	-47	NWT Canada	0.445	Jan
12	S-Cen U.S.	0.339	Jul	-53	-50	-55	NWT Canada	0.328	Jan
14	Panama	0.266	Jul	-69	-66	-71	Panama	0.245	Jul
16	Kenya	0.202	Jan	-73	-68	-79	Kenya	0.190	Jan
18	Kenya	0.145	Jan	-84	-82	-85	Kenya	0.138	Jan
20	Kenya	0.101	Jul	-69	-69	-69	NWT Canada	0.099	Jan
22	Kenya	0.072	Jul	-69	-67	-70	NWT Canada	0.072	Jan
24	New Zealand	0.056	Jul	-55	-48	-65	NWT Canada	0.053	Jan
26	NWT Canada	0.042	Jul	-39	-36	-44	NWT Canada	0.040	Jan
28	NWT Canada	0.028	Jul	-38	-36	-41	NWT Canada	0.029	Jan
30	NWT Canada	0.021	Jul	-35	-34	-38	NWT Canada	0.021	Jan

Table 75. Twenty Percent High Density Extremes for the Worldwide Air Environment – 1 to 30 km

Altitude (km)	Altitude Above Sea Level						Pressure Altitude		
	Density			Temperature (°C)			Density		
	Location (Area)	Value (kg/m³)	Mo.	Mean	Maximum	Minimum	Location (Area)	Value (kg/m³)	Mo.
1	NWT Canada	1.280	Jan	-32	-29	-35	NWT Canada	1.298	Jan
2	NWT Canada	1.118	Jan	-32	-30	-37	NWT Canada	1.146	Jan
4	NWT Canada	0.869	Jan	-39	-32	-47	NWT Canada	0.915	Jan
6	NWT Canada	0.531	Mar	-48	-43	-52	NWT Canada	0.723	Jan
8	New Zealand	0.542	Jul	-46	-40	-51	NWT Canada	0.578	Jan
10	New Zealand	0.426	Jan	-43	-39	-46	NWT Canada	0.442	Jan
12	S-Cer U.S.	0.338	Jul	-52	-50	-54	NWT Canada	0.325	Jan
14	Panama	0.265	Jul	-69	-56	-71	Panama	0.244	Jul
16	Kenya	0.201	Jan	-71	-62	-75	Kenya	0.188	Jan
18	Kenya	0.144	Jan	-83	-78	-89	Kenya	0.137	Jan
20	Kenya	0.097	Jul	-62	-61	-62	NWT Canada	0.098	Jan
22	Kenya	0.070	Jul	-63	-58	-67	NWT Canada	0.072	Jan
24	New Zealand	0.056	Jul	-55	-48	-65	NWT Canada	0.052	Jan
26	NWT Canada	0.042	Jul	-39	-36	-44	NWT Canada	0.039	Jan
28	NWT Canada	0.027	Jul	-37	-32	-43	NWT Canada	0.028	Jan
30	NWT Canada	0.020	Jul	-34	-28	-40	NWT Canada	0.021	Jan

Table 76. Lowest Recorded Density Extremes for the Worldwide Air Environment – 1 to 30 km

Altitude (km)	Altitude Above Sea Level						Pressure Altitude		
	Density			Temperature (°C)			Density		
	Location (Area)	Value (kg/m³)	Mo	Mean	Maximum	Minimum	Location (Area)	Value (kg/m³)	Mo.
1	N-Cen U.S.	1.036	Jul	25	25	25	S-Cen U.S.	1.039	Jul
2	Mid-West U.S.	0.911	Jul	30	31	30	Kenya	0.928	Jan
4	Mid-West U.S.	0.769	Jul	12	12	11	Panama	0.761	Jul
6	Eastern U.S.	0.624	Nov	-17	-17	-17	Panama	0.607	Jan
8	NWT Canada	0.469	Oct	-51	-51	-51	Kenya	0.477	Jul
10	NWT Canada	0.349	Jan	-56	-56	-56	Kenya	0.384	Jan
12	NWT Canada	0.257	Feb	-49	-49	-49	NWT Canada	0.288	Jul
14	NWT Canada	0.189	Feb	-48	-47	-49	NWT Canada	0.210	Jul
16	NWT Canada	0.137	Feb	-43	-43	-43	NWT Canada	0.153	Jul
18	NWT Canada	0.099	Feb	-43	-30	-47	NWT Canada	0.111	Jul
20	NWT Canada	0.071	Feb	-27	-24	-31	NWT Canada	0.081	Jul
22	NWT Canada	0.050	Feb	-32	-32	-32	NWT Canada	0.058	Jul
24	NWT Canada	0.036	Jan	-72	-40	-79	NWT Canada	0.043	Jul
26	N-Cen U.S.	0.022	Jul	-45	-44	-46	NWT Canada	0.020	Jul
28	N-Cen U.S.	0.014	Jul	-44	-42	-49	NWT Canada	0.012	Jul
30	N-Cen U.S.	0.010	Jul	-42	-41	-42	NWT Canada	0.009	Jul

Table 77. One Percent Low Density Extremes for the Worldwide Air Environment – 1 to 30 km

Altitude (km)	Altitude Above Sea Level: Density: Location (Area)	Altitude Above Sea Level: Density: Value (kg/m^3)	Altitude Above Sea Level: Density: Mo.	Altitude Above Sea Level: Temperature (°C): Mean	Altitude Above Sea Level: Temperature (°C): Maximum	Altitude Above Sea Level: Temperature (°C): Minimum	Pressure Altitude: Density: Location (Area)	Pressure Altitude: Density: Value (kg/m^3)	Pressure Altitude: Density: Mo.
1	N-Cen U.S.	1.042	Jul	24	25	23	S-Cen U.S.	1.041	Jul
2	Mid-West U.S.	0.915	Jul	30	31	29	Kenya	0.928	Jan
4	Mid-West U.S.	0.776	Jul	11	11	11	Panama	0.765	Jul
6	Kenya	0.629	Jan	-2	-2	-2	Kenya	0.610	Jan
8	NWT Canada	0.479	Feb	-45	-45	-45	Kenya	0.482	Jul
10	NWT Canada	0.353	Feb	-44	-38	-51	Kenya	0.384	Jan
12	NWT Canada	0.259	Feb	-49	-47	-49	NWT Canada	0.289	Jul
14	NWT Canada	0.190	Feb	-48	-48	-49	NWT Canada	0.211	Jul
16	NWT Canada	0.138	Feb	-43	-43	-44	NWT Canada	0.154	Jul
18	NWT Canada	0.099	Feb	-43	-30	-47	NWT Canada	0.112	Jul
20	NWT Canada	0.071	Feb	-27	-24	-31	NWT Canada	0.032	Jul
22	NWT Canada	0.051	Feb	-37	-37	-27	NWT Canada	0.059	Jul
24	NWT Canada	0.036	Jan	-72	-40	-79	NWT Canada	0.043	Jul
26	N-Cen U.S.	0.023	Jul	-45	-44	-46	NWT Canada	0.021	Jul
28	N-Cen U.S.	0.014	Jul	-44	-42	-49	NWT Canada	0.013	Jul
30	N-Cen U.S.	0.011*	Jul	-42	-41	-42	NWT Canada	0.008	Jul

*Value based on information available at AFCRL (LKI); it is more extreme than the value of 0.014 provided by ETAC.

Table 78. Five Percent Low Density Extremes for the Worldwide Air Environment – 1 to 30 km

Altitude (km)	Altitude Above Sea Level						Pressure Altitude		
	Density			Temperature (°C)			Density		
	Location (Area)	Value (kg/m³)	Mo.	Mean	Maximum	Minimum	Location (Area)	Value (kg/m³)	Mo.
1	Panama	1.047	Jul	23	25	20	S-Cen U.S.	1.048	Jul
2	Mid-West U.S.	0.920	Jul	29	31	28	Kenya	0.931	Jan
4	Mid-West U.S.	0.778	Jul	10	12	8	Kenya	0.768	Jan
6	Kenya	0.632	Jan	-3	-3	-4	Kenya	0.613	Jan
8	NWT Canada	0.485	Mar	-50	-46	-53	Kenya	0.487	Jan
10	NWT Canada	0.357	Mar	-48	-42	-56	Kenya	0.386	Jan
12	NWT Canada	0.262	Mar	-50	-42	-59	NWT Canada	0.289	Jul
14	NWT Canada	0.193	Mar	-49	-41	-60	NWT Canada	0.211	Jul
16	NWT Canada	0.141	Mar	-48	-35	-66	NWT Canada	0.154	Jul
18	NWT Canada	0.102	Feb	-54	-33	-74	NWT Canada	0.112	Jul
20	NWT Canada	0.073	Feb	-60	-25	-75	NWT Canada	0.082	Jul
22	NWT Canada	0.052	Jan	-76	-54	-81	NWT Canada	0.059	Jul
24	NWT Canada	0.036	Jan	-72	-40	-79	NWT Canada	0.043	Jul
26	N-Cen U.S.	0.024	Jul	-45	-44	-46	NWT Canada	0.022	Jul
28	N-Cen U.S.	0.015	Jul	-44	-42	-49	NWT Canada	0.014	Jul
30	N-Cen U.S.	0.012*	Jul	-42	-41	-42	NWT Canada	0.009	Jul

*Value based on information available at AFCRL (LKI); it is more extreme than the value of 0.014 provided by ETAC.

Table 79. Ten Percent Low Density Extremes for the Worldwide Air Environment – 1 to 30 km

Altitude (km)	Altitude Above Sea Level						Pressure Altitude		
	Density			Temperature (°C)			Density		
	Location (Area)	Value (kg/m³)	Mo.	Mean	Maximum	Minimum	Location (Area)	Value (kg/m³)	Mo.
1	Panama	1.048	Jul	22	24	20	S-Cen U.S.	1.050	Jul
2	Mid-West U.S.	0.924	Jul	28	30	26	Kenya	0.935	Jan
4	Mid-West U.S.	0.780	Jul	10	12	8	Kenya	0.769	Jan
6	Kenya	0.634	Jan	-5	-5	-5	Kenya	0.514	Jan
8	NWT Canada	0.492	Mar	-48	-41	-53	Kenya	0.483	Jan
10	NWT Canada	0.358	Mar	-50	-41	-57	Kenya	0.386	Jan
12	NWT Canada	0.264	Mar	-49	-42	-63	NWT Canada	0.289	Jul
14	NWT Canada	0.195	Mar	-53	-43	-67	NWT Canada	0.211	Jul
16	NWT Canada	0.142	Mar	-51	-38	-72	NWT Canada	0.154	Jul
18	NWT Canada	0.103	Feb	-52	-34	-74	NWT Canada	0.112	Jul
20	NWT Canada	0.075	Jan	-78	-67	-83	NWT Canada	0.082	Jul
22	NWT Canada	0.053	Jan	-77	-42	-83	NWT Canada	0.059	Jul
24	NWT Canada	0.037	Jan	-78	-70	-83	NWT Canada	0.043	Jul
26	N-Cen U.S.	0.024	Jul	-46	-42	-50	NWT Canada	0.022	Jul
28	N-Cen U.S.	0.015	Jul	-44	-42	-49	NWT Canada	0.014	Jul
30	N-Cen U.S.	0.013*	Jul	-42	-41	-42	NWT Canada	0.009	Jul

*Value based on information available at AFCRL (LKI); it is more extreme than the value of 0.014 provided by ETAC.

Table 80. Twenty Percent Low Density Extremes for the Worldwide Air Environment – 1 to 30 km

Altitude (km)	Altitude Above Sea Level						Pressure Altitude		
	Density			Temperature (°C)			Density		
	Location (Area)	Value (kg/m³)	Mo.	Mean	Maximum	Minimum	Location (Area)	Value (kg/m³)	Mo.
1	Panama	1.051	Jul	22	23	22	S-Cen U.S.	1.052	Jul
2	Mid-West U.S.	0.928	Jul	27	29	25	Kenya	0.942	Jan
4	Mid-West U.S.	0.782	Jul	9	11	6	Kenya	0.771	Jan
6	Kenya	0.635	Jan	-5	-3	-7	Kenya	0.616	Jan
8	NWT Canada	0.499	Mar	-51	-46	-59	Kenya	0.490	Jan
10	NWT Canada	0.362	Mar	-48	-38	-60	Kenya	0.388	Jan
12	NWT Canada	0.266	Mar	-4[illegible]	-40	-61	NWT Canada	0.289	Jul
14	NWT Canada	0.197	Mar	-54	-43	-70	NWT Canada	0.211	Jul
16	NWT Canada	0.145	Mar	-56	-40	-70	NWT Canada	0.1[illegible]	Jul
18	NWT Canada	0.105	Jan	-71	-43	-80	NWT Canada	0.1[illegible]	Jul
20	NWT Canada	0.075	Jan	-73	-48	-82	NWT Canada	0.082	Jul
22	NWT Canada	0.053	Jan	-77	-42	-83	NWT Canada	0.059	Jul
24	NWT Canada	0.037	Jan	-78	-70	-83	NWT Canada	0.043	Jul
26	N-Cen U.S.	0.025	Jul	-46	-42	-50	NWT Canada	0.024	Jul
28	N-Cen U.S.	0.016	Jul	-44	-42	-49	NWT Canada	0.015	Jul
30	N-Cen U.S.	0.013*	Jul	-42	-41	-42	NWT Canada	0.009	Jul

*Value based on information available at AFCRL (LKI); it is more extreme than the value of 0.014 provided by ETAC.

During the remainder of the program, the observational network consisted of six stations located along the east coast of North America plus a station at Boulder, Colorado (1966 Aug through 1967 Jun), and a special series of flights at Thule, Greenland in January 1966. The data from this smaller network of stations were obtained from soundings using the Mast electrochemical ozonesonde.

Ozone observations were made once a week on Wednesday at 1200 GMT and, because of balloon limitations, did not exceed 30 km.

Climatological summaries of mean ozone amounts from this network were published, but they do not give an estimate of the extreme values of ozone required for MIL-STD-210B. Values of the maximum, and 1 and 10 percent ozone extremes are provided herein. The maximum and 10 percent extremes were provided by Borden[74] and the 1 percent is an estimate by Kantor[75] to obtain the customary design value.

Borden determined the maximum and 10 percent extreme by examining 737 Mast ozonesonde profiles and 791 Regener profiles. All of these profiles were divided into 2-km intervals. The highest value of ozone found in the profiles for each interval was recorded and the amounts equalled or exceeded by 10 percent of the observations for each altitude interval were determined. These values were plotted against altitude and are presented in Figure 30.

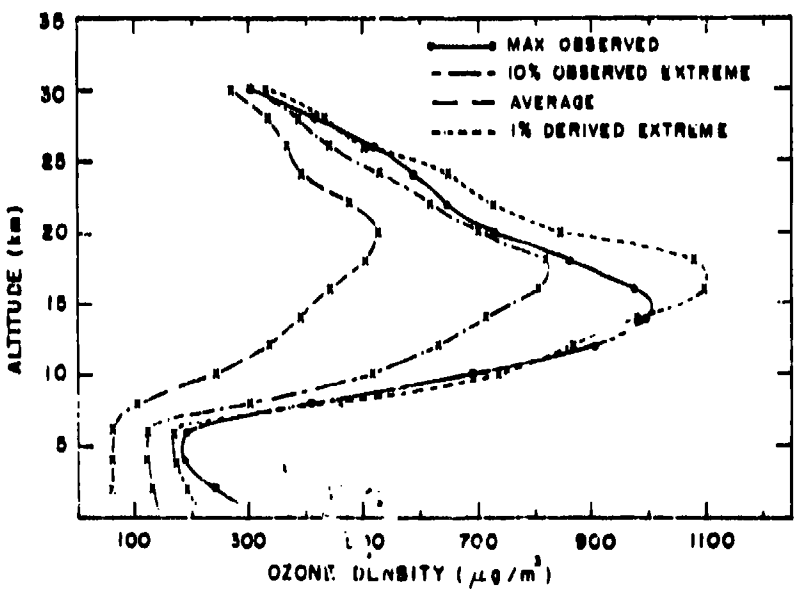


Figure 30. Ozone Concentration Extremes (Maximum and 1 and 10 Percent Extremes) as a Function of Altitude Up to 30 km

Also portrayed on Figure 30 are average ozone densities, and 1 percent estimated extremes determined by Kantor. One percent ozone extremes were estimated for each 2-km interval utilizing the 50 percent and the 10 percent values by assuming that ozone density observations from a particular station and at a particular height have a normal distribution as described in Section I. 2. 3. The so-determined average and 1-percent extremes were then plotted and graphed versus altitude. The extrapolated 1-percent values are more severe than the maximum observed values at a number of altitudes. This is undoubtedly due to the relatively small data sample at just a few widely scattered locations around the Northern Hemisphere.

Potential users of design values presented in Table 81 are cautioned that the values do not occur simultaneously in time or space and that they are essentially representative of the 75 Meridian.

Table 81. Ozone Extremes at Altitudes Up to 30 km

km	$\mu g/m^3$		
	Maximum Observed	1%	10%
1	280	205	140
2	340	190	130
4	185	170	120
6	190	170	120
8	410	460	300
10	690	735	515
12	905	865	630
14	1000	975	715
16	975	1100	805
18	860	1075	820
20	730	845	700
22	645	730	615
24	500	630	530
26	520	505	440
28	415	430	385
30	300	330	300

Maximum and 10 percent extremes shown in Figure 30 were observed in the following locations and seasons:

(1) 2 to 4 km – late spring to early summer in middle latitudes;

(2) 6 to 22 km – spring at latitudes from 40° to 60°N and associated with large amplitude troughs of low pressure in which the ozone was transported to the south and to lower elevations.

(3) 24 to 26 km – latitudes from 45° to 80°N during the winter and associated with "explosive warming" situations during which tropical ozone amounts at 28 to 30 km were carried to the north and downward to these levels;

(4) 28 to 30 km – the tropics during latter part of spring season.

1.7.1 HIGHEST RECORDED

The highest observed ozone density in Table 81 is about 1000 $\mu g/m^3$ at a height of 14 km.

1.7.2 OPERATIONS

The 1 percent extremes mandatory for operation at the various levels are provided in Table 81. Also included for reference are the 10 percent extremes.

2. ALTITUDES 98,000 FT (30 km) TO 262,000 FT (80 km)

Information on extreme temperatures, dew points, winds, pressures, densities, etc. that are likely to occur at various levels in the stratosphere and mesosphere is frequently needed by engineers for consideration in the design of aerospace vehicles. The limited number and uneven geographical distribution of measurements of atmospheric properties for levels above 30 km make it difficult for meteorologists to provide accurate values of such extremes.

Best estimates of such extremes* have been provided in various research studies by members of the Design Climatology Branch (LKI) of AFCRL. Extremes presented in this section are taken from these reports.

Only highest/lowest observed and operational extremes are presented in this section. The withstanding concept is not applicable in the upper air; that is, military equipment will not be stored or be in a standby status in the free atmosphere.

2.1 Temperature

Extremes of temperature (pressure and density) for altitudes above 30 km were prepared by Cole[76,77] for MIL-STD-210 revision by examining frequency

*Because of the paucity of data at those altitudes, such extremes cannot be interpreted as the number of hours per month that a given value of a climatic element is equalled or surpassed as described in Section 1.2.3.

76. Cole, A. E. (1970) Extreme Temperature, Pressure and Density Between 30 and 80 km, AFCRL-70-0467, ERP 330, 31 pp.

77. Cole, A. E. (1972) Distribution of Thermodynamic Properties of the Atmosphere Between 30 and 80 km, AFCRL-72-0477, ERP 409.

distributions of observed temperatures between 30 and 80 km and extrapolating to obtain estimates of the worldwide extremes. He obtained estimates of high and low temperatures that are equalled or surpassed during 1, 10, and 50 percent of the time during the warmest and coldest months, respectively.

Models which have been developed to illustrate latitudinal and seasonal variations in atmospheric structure between 30 and 80 km show that the most extreme temperature values occur in polar regions. Between 30 and 65 km, the warmest temperatures occur over the summer pole, and the coldest over the winter pole. Between 65 and 80 km, the situation is reversed, and the temperatures are coldest in summer and warmest in winter.

Most of the available data for determining distributions of thermodynamic properties of the atmosphere at levels between 30 and 80 km are from meteorological and experimental rocket soundings in the northern hemisphere. Few observations are available for polar regions where the most extreme values occur.

Routine daily Meteorological Rocket Network (MRN) observations for the years 1965 to 1969 were used to investigate the frequency distributions of temperature (pressure, and density) at levels between 30 and 55 km. The measurements considered were taken within a few hours of local noon.

At high- and mid-latitude sites, June and July observations are used to represent high temperature extremes; December and January observations represent the low extremes. The use of the data for two calendar months, rather than one, greatly increased the sample size and the reliability of the estimates with little effect on extreme values. Sample sizes for a given level vary from 35 to 100 observations depending on season and location.

Extremes for levels between 55 and 80 km are based primarily on data derived from aroradio grenade, falling sphere, and pitot-static tube experiments performed between 1958 and 1970 at ten locations. A significant number of observations at these levels were taken in February and August. Consequently, observations taken during the first 10 days of February and August were included with the December-January and June-July data to enlarge the sample size at sites between 30 and 75°N. Only seasonal means could be computed from the sparse data for tropical areas. These means were estimated by fitting an annual curve to data derived from scattered grenade and pitot-static tube experiments conducted at Ascension Island 8°S and Natal 6°S.

Figures 31 through 34 from Cole[77] show temperature extremes as a function of altitude, latitude, and time of year. From these data Cole subjectively determined for the various altitudes the 1, 10, and 50 percent extremes that would be experienced in the worst location during the worst season (2-month period). These estimated worldwide extremes (Antarctic excluded) presented in Table 82 are based on extrapolated data and are in most cases more extreme than those observed at any of the observational sites.

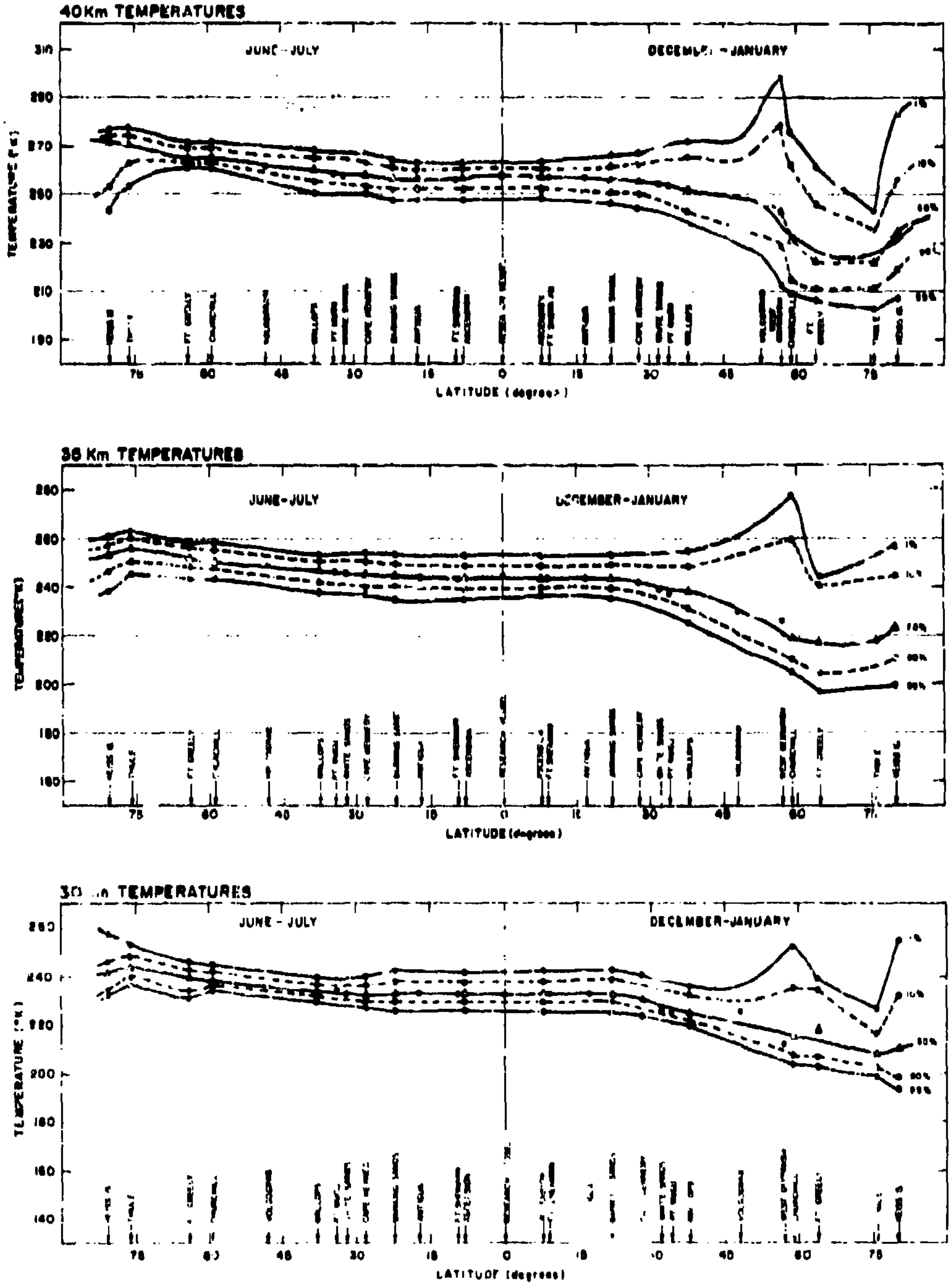


Figure 31. Median (50 Percent) and 10 and 1 Percent Extreme High and Low Temperatures as a Function of Latitude for Altitudes of 30, 35, and 40 km. Triangles represent median values and circles seasonal mean values. (At 40 km, a smoothed median curve is also given.)

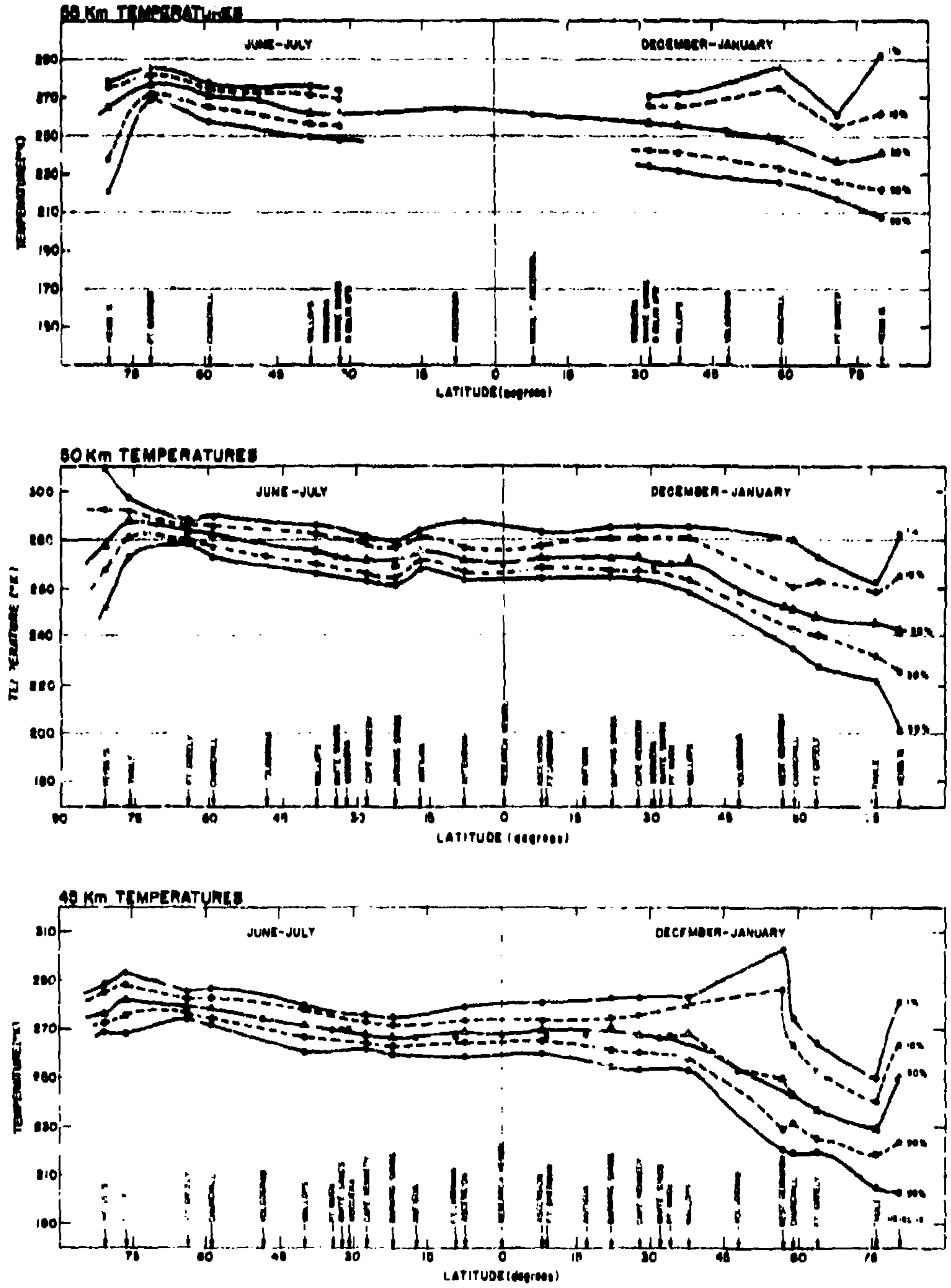


Figure 32. Median (50 Percent) and 10 and 1 Percent Extreme High and Low Temperatures as a Function of Latitude for Altitudes of 45, 50, and 55 km. Triangles represent median values and circles seasonal mean values. (At 45 km, a smoothed median curve is also given.)

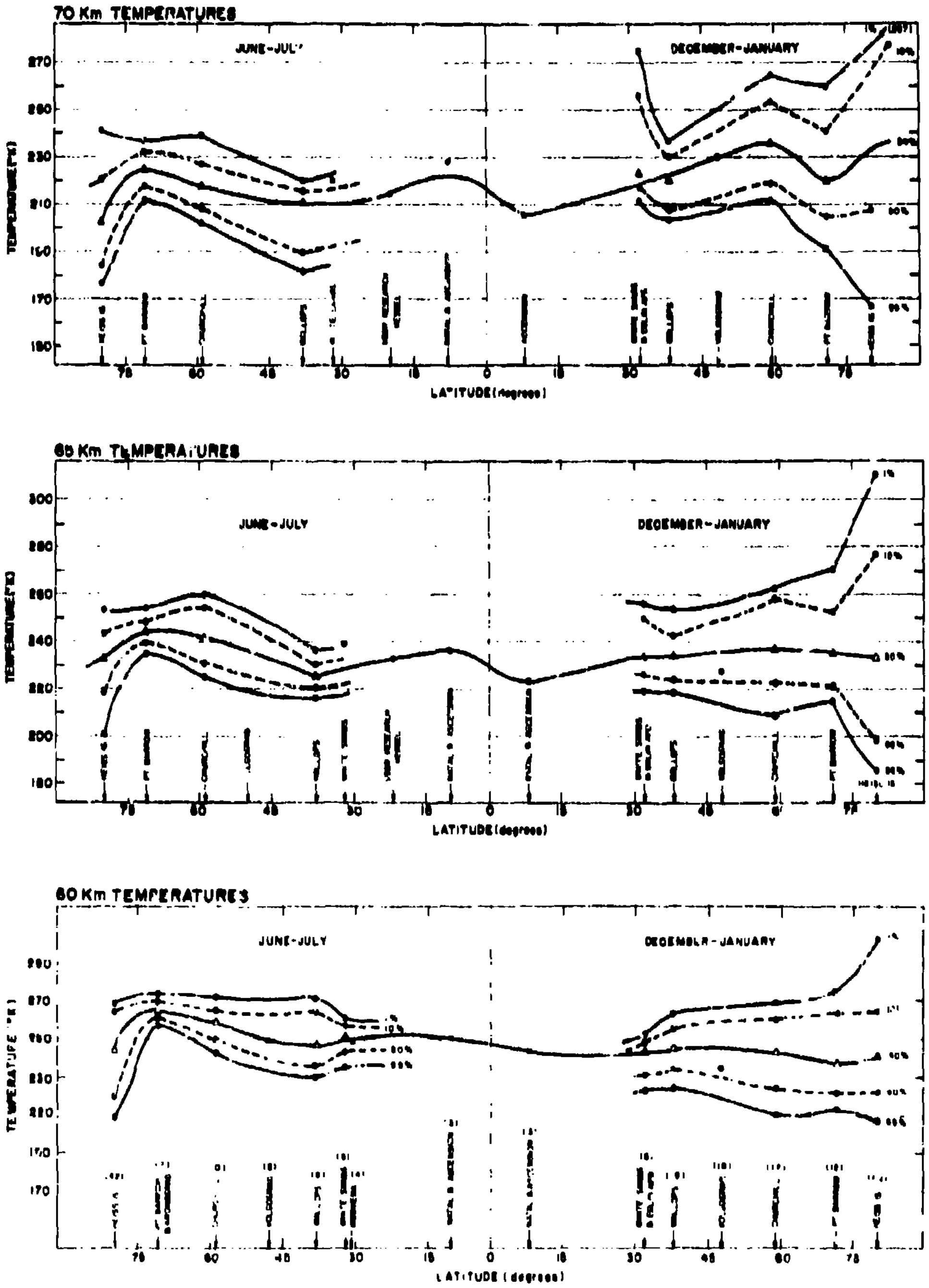
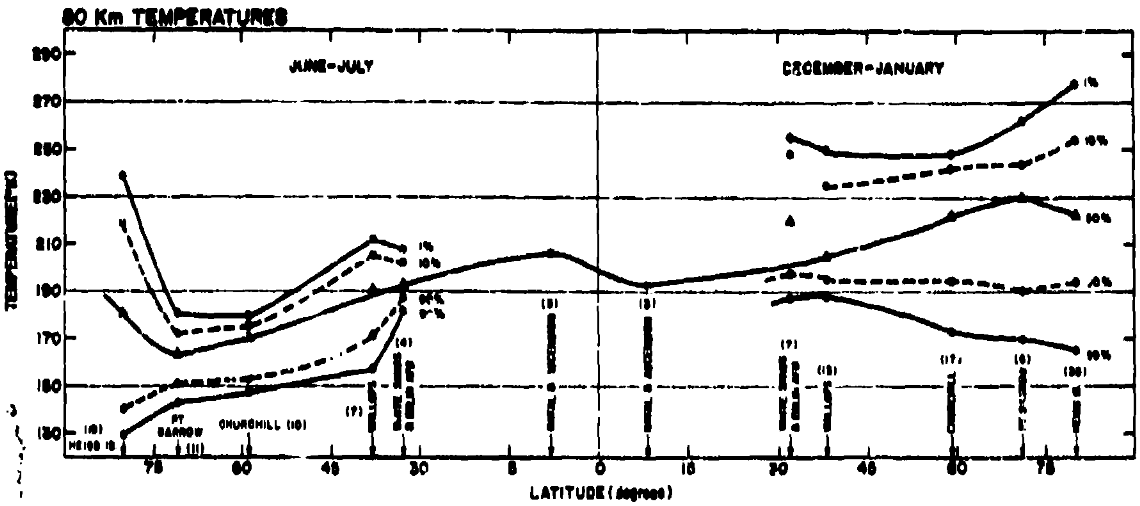


Figure 33. Median (50 Percent) and 10 and 1 Percent Extreme High and Low Temperatures as a Function of Latitude for Altitudes of 60, 65, and 70 km. Triangles represent median values and circles seasonal mean values. (Number of available observations is given in parentheses at the 60 km level.)



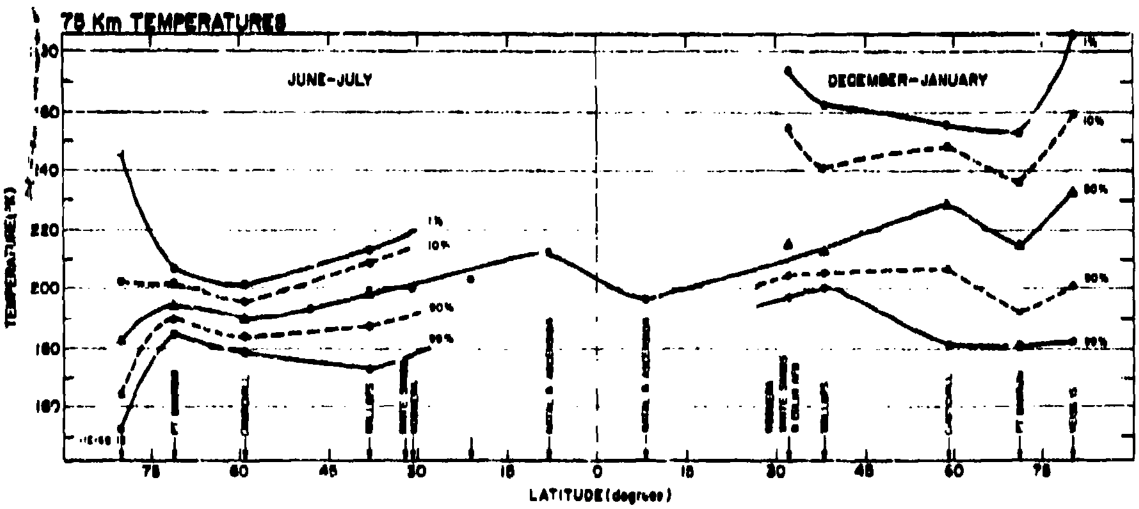


Figure 34. Median (50 Percent) and 10 and 1 Percent Extreme High and Low Temperatures as a Function of Latitude for Altitudes of 75 and 80 km. Triangles represent median values and circles seasonal mean values. (Number of available observations is given in parentheses at the 80 km level.)

Table 82. High and Low Temperature Extremes for 30 to 80 km Geometric Altitude

Altitude (km)	High Temperatures (°C) 1%	High Temperatures (°C) 10%	Low Temperatures (°C) 1%	Low Temperatures (°C) 10%
30	-11	-24	-79	-75
35	3	-13	-74	-63
40	25	5	-70	-62
45	30	15	-70	-54
50	37	20	-70	-49
55	19	8	-64	-52
60	29	-3	-64	-5[illegible]
65	37	3	-87	-75
70	24	4	-107	-90
75	16	-14	-120	-110
80	5	-19	-145	-133

These worldwide extremes of temperature for altitudes between 30 and 80 km are conservative estimates, as they are based on observations which include random instrumentation errors. Greater confidence can be placed in the values for levels below 50 km, where the sample sizes are larger and the magnitude of the random instrumentation errors has been evaluated.

Observations of temperatures for levels between 30 and 80 km approach a normal distribution in summer. In winter, temperature tends to have bimodal or rectangular distribution at high- and mid-altitudes.

Since both high and low worldwide extremes are found near the poles, additional rocket observations are needed in these regions for more refined estimates of extremes between 30 and 80 km.

2.1.1 HIGH TEMPERATURE

High temperature extremes for altitudes of 30 to 80 km are provided in Table 82.

2.1.1.1 Highest Recorded

Cole did not list the highest observed temperatures for the various altitudes. Because of the small sample size, these values are generally less extreme than the estimated 1 percent extremes.

2.1.1.2 Operations

The 1 and 10 percent high temperature extremes are listed for various altitudes in Table 82. The highest value is +37°C at an altitude of 65 km.

2.1.1.3 Associated Densities

Cole,[78] in a separate study, provided densities associated with the 1 percent extreme high and low temperatures. These are given in Table 83. He indicated that there was no unique density associated with an extreme temperature. The density values provided are typical values (observed or estimated) that are likely to occur with the given temperature extremes. Densities up to 15 percent higher and lower should be considered in design if values in Table 83 are near critical.

Table 83. Densities Associated with the 1 Percent High and Low Temperature Extremes for 35 to 80 km Geometric Altitude

Altitude (km)	Density (kg/m^3)	
	With 1% High Temp.	With 1% Low Temp.
35	6.146×10^{-3}	7.223×10^{-3}
40	3.115	3.170
45	1.402	1.660
50	0.997	0.723
55	0.292	0.681
60	0.176	0.282
65	0.101	0.126
70	0.055	0.046
75	0.015	0.020
80	0.007	0.006

2.1.2 LOW

Low temperature extremes for altitudes of 30 to 80 km are also provided in Table 82.

2.1.2.1 Lowest Recorded

See Section 2.1.1.1.

2.1.2.2 Operations

The 1 and 10 percent low temperature extremes are listed for various altitudes in Table 82. The lowest 1 percent temperature is -145°C at 80 km.

2.1.2.3 Associated Densities

See Section 2.1.1.3.

78. Cole, A.E. (1973) Densities Associated with Temperature Extremes and Vice-Versa, Personal Communication, AFCRL (LKI).

2.2 Absolute Humidity

See Section II. 2. for a general discussion of atmospheric humidity and Section IV. 1. 2 for a discussion of the effects of water vapor aloft on military equipment. Grantham and Sissenwine[21] studied extremes of high water vapor content up to 80 km; the details of their study are included in Section IV. 1. 2. 1. 1.

2. 2. 1 HIGH ABSOLUTE HUMIDITY

2. 2. 1. 1 Highest Recorded

Not available.

2. 2. 1. 2 Operations

For altitudes of 30 km and above, Grantham and Sissenwine list the following 1 percent operational high frost point extremes which have a one-to-one relationship with absolute humidity:

Height (km)	1 Percent Frost Point (°C)
30	-67.5
35	-73.0
40	-78.5
45	-84.0
50	-89.5
55	-95.0
60	-100.5
65	-106.0
70	-111.5
75	-117.0
80	-122.5

2. 2. 2 LOW ABSOLUTE HUMIDITY

Not available.

2.3 Wind

The material in this section is taken from Kantor.[79,56]

Strong wind and vertical wind shear (change in horizontal wind velocity with altitude) have long been meteorological problems affecting conventional aircraft flight and missile design and operation in the upper troposphere and lower stratosphere. They must also be considered for design and operation of vehicles that will operate in or penetrate the upper stratosphere (above 30 km) and mesosphere. Large shears, for example, produce forces on aerospace vehicles which alter their altitude, pointing them in the wrong direction and resulting, possibly, in

79. Kantor, A.J. (1969) Strong Wind and Vertical Wind Shear Above 30 km, AFCRL-69-0346, ERP 303, 13 p.

excessive heating due to unplanned angles of attack Large shears can also be significant during staging above 30 km; that is, separation of a booster from its main vehicle on ascent, since aerodynamic instability may occur temporarily during this maneuver. Consequently, extreme wind and wind shear values above 30 km may be critical for some design and in some operation of aerospace systems, present and future. Critical values will vary with the design of the individual aerospace vehicle.

The 1, 5, and 10 percent wind extremes are provided for altitudes between 30 and 80 km. These winds have been derived primarily from data in the Northern Hemisphere. Percent extremes are for the windiest month and region.

Wind shears, also provided as 1, 5, and 10 percent extremes, must be considered as only very rough first estimates. They have been based on scattered data at a few locations, primarily in the Northern Hemisphere, for which observations permit crude estimation of 1-km shears between 30 and 70 km. All data, regardless of day or month of occurrence, were pooled due to the restricted sample size. Consequently, shear values could not be closely related to either a month or location of maximum shears.

The bulk of data available for the study of wind speed extremes consisted of wind observations above 30 km from more than 30 Northern Hemisphere locations stretching from approximately 9 to 77°N, and described in the monthly data reports of the Meteorological Rocket Network (MRN). Observations encompassing up to eight years of winds at several of the North American stations were derived from a variety of sensors, but primarily from parachute-borne instruments launched by rockets.

Useable data for the wind shear portion of this study were more severely limited than for winds since the aerodynamics of parachutes, the most popular sensor for winds, are such that much of the difference between wind vectors in adjacent layers could be due to gliding or sailing of the parachute. Also, altitude intervals for which data are provided by chute-borne sensors are too coarse for determination of 1-km or smaller vertical wind shears. As a result, wind shear estimates have been based on only a few series of detailed FPS-16 radar tracked ROBIN (an inflated 1-m plastic sphere) sensors. ROBIN soundings, initiated in 1960 from six stations, are tabulated below:

Location		No. of ROBIN Soundings	No. of 1-km or 3000-ft Shears
Ascension Island	(8°S)	32	1296
Kwajalein Island	(9°N)	11	273
Cape Kennedy, Fla.	(28°N)	21	746
Eglin AFB, Fla.	(30°N)	161	5044
Holloman AFB, N. M.	(33°N)	19	509
Wallops Island, Va.	(38°N)	14	397

2.3.1 WIND SPEED

Kantor, using the observations described above, constructed vertical cross sections of mean monthly zonal (east-west) and meridional (north-south) winds to determine the month and location having the strongest winds for the various levels. Mean monthly wind vectors were computed from the estimated component winds, and the resulting wind vectors were found to be largest during the winter months and north of 35°N. Standard deviations of the component winds for these months, based on data for locations within this region, were used to estimate the vector standard deviations of the monthly winds for the windiest locations in the Northern Hemisphere. Using the vector means and their associated vector standard deviations and assuming a circular normal distribution, the 1, 5, and 10 percent scalar wind speed extremes were calculated with the nomograph provided by Crutcher.[80,*] The largest 1, 5, and 10 percent scalar wind speed (mps) extremes (with some smoothing of the data) are shown in Table 84.

Table 84. Wind Speed Extremes for 30 to 80 km Geometric Altitude

Altitude (km)	1% (mps)	5% (mps)	10% (mps)
30	124	102	90
35	150	126	113
40	200	163	144
45	210	182	167
50	213	186	175
55	213	185	170
60	180	158	146
65	169	151	140
70	165	145	133
75	145	126	115
80	145	125	114

These estimated 1, 5, and 10 percent extremes include rms errors in wind speed of roughly 4 mps.

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*This is a procedure similar to that described in Section 1.2.3 but applicable to vector quantities.

80. Crutcher, H.L. (1959) Upper Wind Statistics Charts of the Northern Hemisphere, NAVAER 50-1C-535, Vol. I and II.

2.3.1.1 Highest Recorded

Kantor did not list the highest observed wind speeds for the various altitudes. Because of the small sample size, these values are generally less extreme than the estimated 1 percent extremes.

2.3.1.2 Operations

Estimated 1, 5, and 10 percent wind speed extremes for the windiest months and latitudes in the Northern Hemisphere are shown in Table 84. Speed increases up to roughly 50 km and appears to decrease thereafter up to at least 75 or 80 km. Although insufficient information is available, it is generally believed that values tend to increase again with altitude up to at least 120 km. As can be seen from the table, the 1 percent wind speed extreme can be expected to reach 213 mps at 50 to 55 km at the windiest latitude and during the windiest months.

For comparison, estimates of 1, 5, and 10 percent wind speed extremes over the Southern Hemisphere for altitudes 30 to 60 km were also determined by Kantor. These winds appear to reach a maximum between 50 and 55 km, or approximately the same altitudes as for the Northern Hemisphere. For the percent extremes provided, Southern Hemisphere values are generally somewhat smaller than Northern Hemisphere values, with the 1 percent wind speed extreme attaining 200 mps between 52 and 54 km. However, the Southern Hemisphere estimates were based on a very small amount of data pooled from six widely scattered locations so that they are not necessarily representative of either the windiest month or location. Until more data is available from the Southern Hemisphere, the values listed in Table 84 are recommended as worldwide extremes.

The values in Table 84 were determined statistically without regard either to location or interlevel correlation at any given location. Consequently, they represent envelopes rather than realistic vertical wind profiles.

2.3.2 WIND SHEAR

Wind shear data for the six stations noted earlier and frequency distributions of 1-km and 3000-ft (914 m) shears for altitudes between 30 and 70 km were available to Kantor in Salmela and Sissenwine.[81] Frequency distributions of these shears were used to estimate (see Section I.2.3) 1, 5, and 10 percent 1-km shear extremes for each of the four 10-km altitude intervals between 30 and 70 km at the six locations.

Frequency distributions provided by Salmela and Sissenwine[81] for Cape Kennedy included 1-km shears computed for all possible (overlapping) 1-km (approximately) intervals in addition to consecutive 1-km intervals. This had the

81. Salmela, H.A., and Sissenwine, N. (1969) Distribution of ROBIN Sensed Wind Shears at 30 to 70 Kilometers. AFCRL-69-0053, ERP 298.

effect of increasing the sample size at Cape Kennedy by about a factor of three. It also produced larger shear values which were not evident in the smaller, consecutive 1-km sample. The 1, 5, and 10 percent shear extremes at Cape Kennedy (pooling data from all levels) computed for both overlapping and non-overlapping/consecutive intervals and the ratios of the overlapping shears to the non-overlapping shears are:

Percent Extreme	Shears (m/sec/km)		
	Overlapping	Non-Overlapping	Ratio
1	28.0	24.8	1.13
5	16.8	15.4	1.09
10	13.9	12.9	1.08

Kantor applied these ratios (1.13; 1.09; 1.08) to the previously computed 1, 5, and 10 percent shear extremes at all six stations to provide more realistic estimates of 1, 5, and 10 percent wind shear extremes.

2.3.2.1 Highest Recorded

See note in Section 2.3.1.1.

2.3.2.2 Operations

Estimated 1, 5, and 10 percent n st extreme month, 1-km vertical wind shear extremes and the latitudes at which they occur are shown in Table 85.

Table 85. Wind Shear Extremes for 30 to 70 km Geometric Altitude. (Numbers in Parentheses are Latitudes Where Shears Were Maximum)

Height (km)	Wind Shear (m/sec/km)		
	1%	5%	10%
30-39	51 (38°N)	18 (38°N)	15 (38°N)
40-49	46 (33°N)	21 (33°N)	17 (33°N)
50-59	42 (30°N)	24 (30°N)	19 (9°N)
60-69	121 (9°N)	85 (9°N)	76 (9°N)

The 1, 5, and 10 percent 1-km shear values generally increase with altitude up to 70 km, and the latitude of maximum shears tends to move equatorward with increasing altitude. The above estimates, however, represent only very rough first approximations, since they have been based on just a few sporadic observations at the six locations described earlier. Although they are estimated from one sensor

(ROBIN sphere), winds were not necessarily observed during the same months or years at any of the stations, nor could these values be related to either a month or location of maximum shears.

Rms wind vector errors for the ROBIN sphere range from about 1/2 mps below 50 km to 3 mps between 60 and 70 km. If wind vector errors can be assumed to be uncorrelated, the rms error in shear is 1.414 times the wind vector error. Thus rms errors are no larger than roughly 1/10 the magnitude of the shears in Table 85.

In the addendum to Kantor,[79] Kantor reports that since August 1969 further progress on vertical wind shear above 30 km was made using observations at a seventh location, Antigua AAFB, BWI (17°N), and additional data for Ascension Island and Cape Kennedy. The revised shear analyses did not significantly change the estimates of 1, 5, and 10 percent 1-km wind shear extremes.

2.4 Pressure

Extremes of pressure for altitudes above 30 km were prepared by Cole[76,77] for the MIL-STD-210 revision. Cole examined the distributions of pressures (derived from temperature and density measurements) between 30 and 80 km and extrapolated these distributions to obtain estimates of the worldwide extremes. He obtained estimates of high and low pressures that are equalled or surpassed during 1, 10, and 50 percent of the time of the months with highest and lowest pressures respectively.

Models which have been developed to illustrate latitudinal and seasonal variations in atmospheric structure between 30 and 80 km show that the most extreme pressures occur in polar regions. The highest pressures are observed in summer when the circulation pattern is dominated by an anticyclone centered over the pole; lowest values are associated with a polar cyclone which is normally centered off the eastern coast of northern Greenland in winter.

Figure 35 presents his results and shows the variation with latitude of extremes of pressure for different altitudes. Smoothed curves extending from pole to equator at levels below 55 km are subjectively fitted to the data points to provide estimates of extreme values at other latitudes. As expected, the extreme values of pressure at mid and high latitudes fall on either side of the U.S. Standard Atmosphere values, represented by the zero departure lines in each figure.

Above 50 km, pressure extremes were derived from distributions for three sites—Churchill, Point Barrow, and Heiss Island. The frequency distribtions at each of the two sites are based on observations taken during a two-month period.

An examination of data derived from grenade, pressure gage, and falling sphere experiments at Point Barrow and Churchill, and meteorological rockets

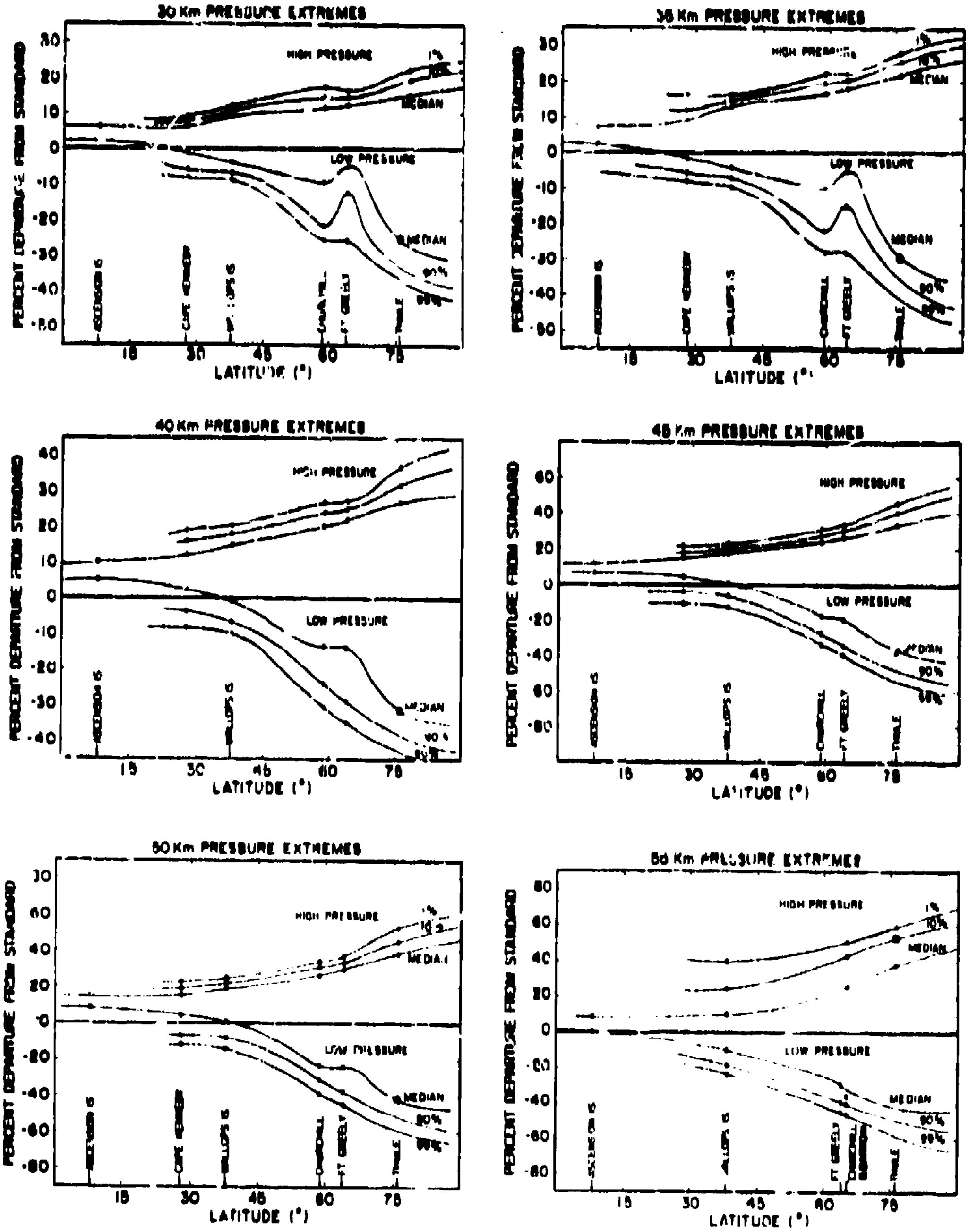


Figure 35. Median (50 Percent) and 10 and 1 Percent Extreme High and Low Pressure as a Function of Latitude for Altitudes of 30 to 55 km

at Heiss Island indicate that mean seasonal values of pressure are highest in summer and lowest in winter at levels between 50 and 80 km.

The estimated worldwide extremes (Antarctic area excluded) of pressure for altitudes between 30 and 80 km are considered to be conservative estimates, as they are based on observations which include random instrumentation errors.

Since both high and low worldwide extremes are found near the poles, additional rocket observations are needed in these regions for more refined estimates of extremes between 30 and 80 km.

2.4.1 HIGH PRESSURE

High pressure extremes for altitudes of 30 to 80 km are provided in Table 86.

Table 86. High and Low Pressure Extremes for 30 to 80 km Geometric Altitude

Altitude (km)	High Pressure (mbs)		Low Pressure (mbs)	
	1%	10%	1%	10%
30	14.8	14.5	6.94	7.42
35	7.64	7.41	3.05	3.39
40	4.07	3.93	1.49	1.66
45	2.23	2.17	0.670	0.700
50	1.24	1.19	0.311	0.390
55	0.709	0.658	0.163	0.179
60	0.386	0.350	0.0741	0.0808
65	0.194	0.175	0.0364	0.0423
70	0.0855	0.0806	0.0165	0.0204
75	0.0372	0.0342	0.0080	0.0105
80	0.0153	0.0139	0.0035	0.0047

2.4.1.1 Highest Recorded

Cole did not list the highest observed pressures for the various altitudes. Because of the small sample size, these values are generally less extreme than the estimated 1 percent extremes.

2.4.1.2 Operations

The 1 and 10 percent probable high pressure extremes are listed in Table 86 for various altitudes.

2.4.2 LOW PRESSURE

Low pressure extremes for altitudes of 30 to 80 km are also provided in Table 86.

2.4.2.1 Lowest Recorded

See Section 2.4.1.1.

2.4.2.2 Operations

The 1 and 10 percent low pressure extremes are listed in Table 88.

2.5 Density

Extremes of density for altitudes above 30 km were prepared by Cole[76,77] for MIL-STD-210 revision.

Cole examined the distributions of density (derived from temperature measurements) between 30 and 80 km and extrapolated to obtain estimates of the worldwide extremes. He obtained estimates of high and low densities that are equalled or surpassed during 1, 10, and 50 percent of the time of the months with highest and lowest densities respectively.

Models which have been developed to illustrate latitudinal and seasonal variations in atmospheric structure between 30 and 80 km show that the most extreme densities occur in polar regions. The highest densities are observed in summer when the circulation pattern is dominated by an anticyclone centered over the pole; lowest values are associated with a polar cyclone which is normally centered off the eastern coast of northern Greenland in winter.

Section 2.1 discusses the data used by Cole to determine the 1, 10, and 50 percentile values for the latitudes and months with the highest and lowest densities. Figures 36 through 39 present his results and show the variation with latitude of extremes of density for different altitudes. Smoothed curves extending from pole to equator at levels below 50 km, and from pole to 30° latitude at levels above 50 km are subjectively fitted to the data points to provide estimates of extreme values at other latitudes. As expected, the extreme high and low values of density at mid and high latitudes fall on either side of the U.S. Standard Atmosphere values, represented by the zero departure lines in each figure.

Latitudinal curves of density extremes above 50 km are fitted to values derived from distributions for seven sites between 30 and 85°N latitude and mean seasonal values derived from scattered data in tropical areas. As noted in Section 2.1, the frequency distributions at each site between 30 and 70°N are based on observations taken during June-July and December-January plus the first ten days of August and February; such densities average 2 to 3 percent greater in winter and 1 to 3 percent less in summer than those based on two months.

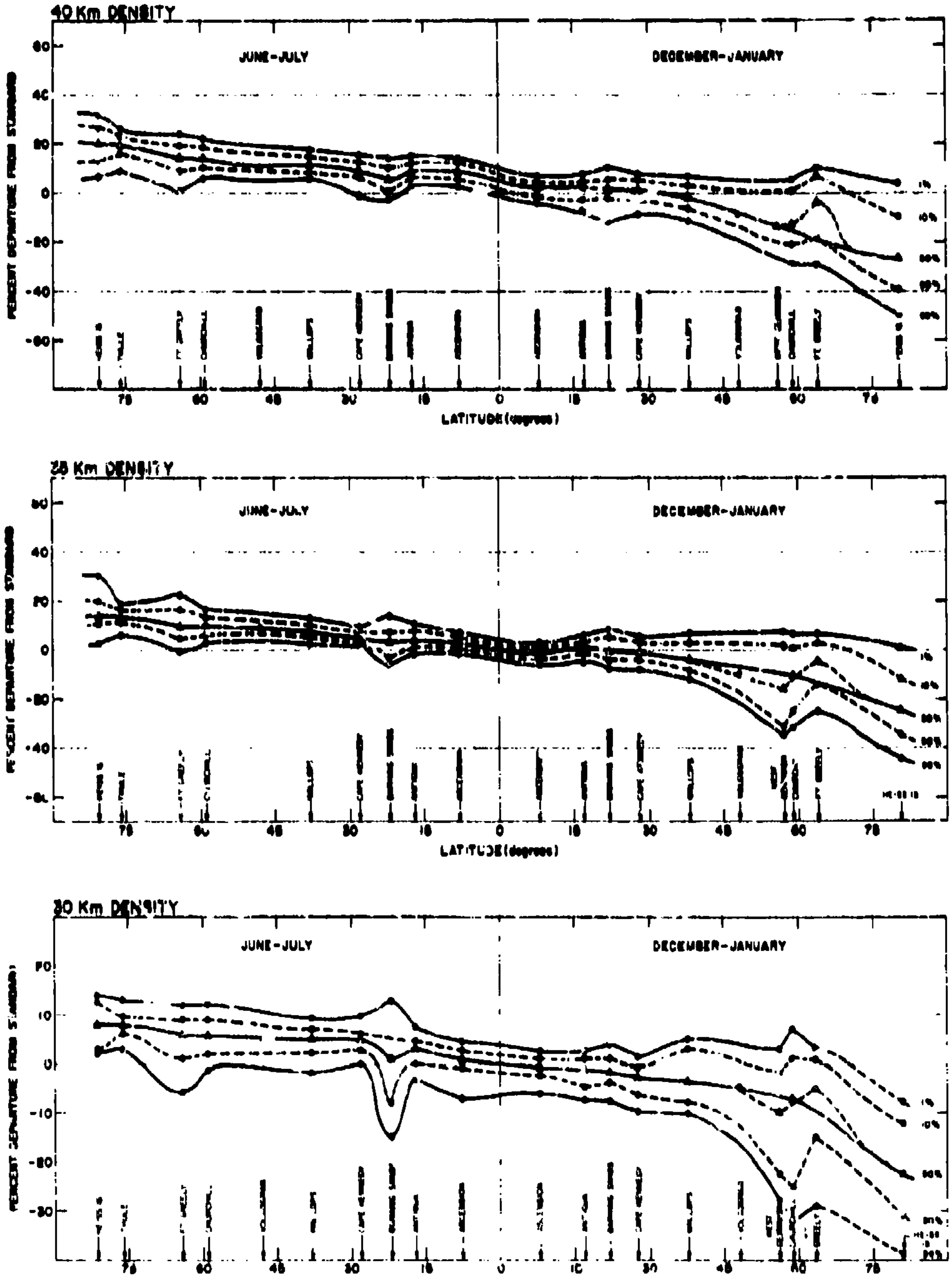


Figure 36. Median (50 Percent) and 10 and 1 Percent Extreme High and Low Density as a Function of Latitude for Altitudes of 30, 55, and 40 km. Triangles represent median values and circles seasonal mean values. (Both smoothed and unsmoothed median curves are given.)

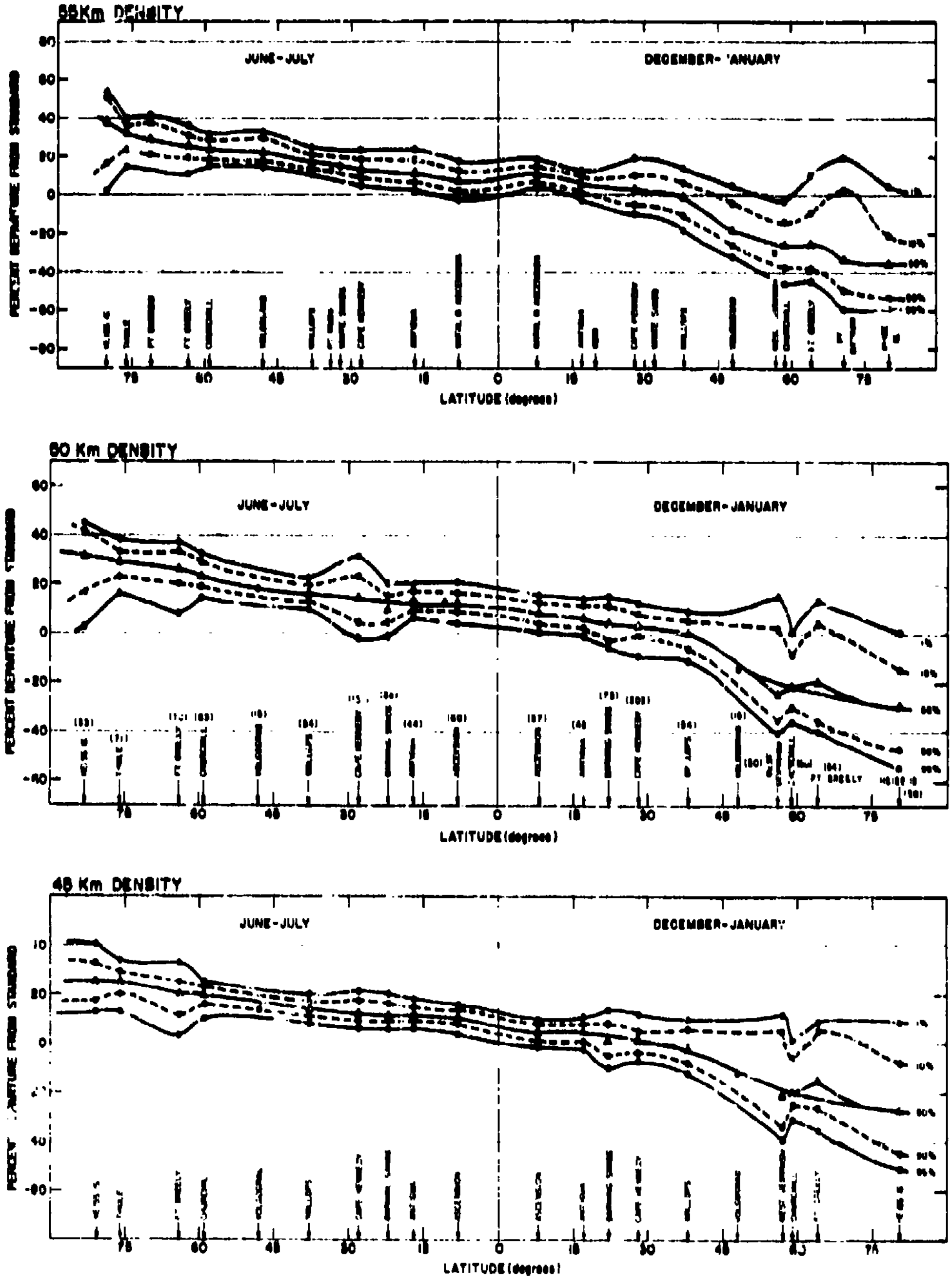
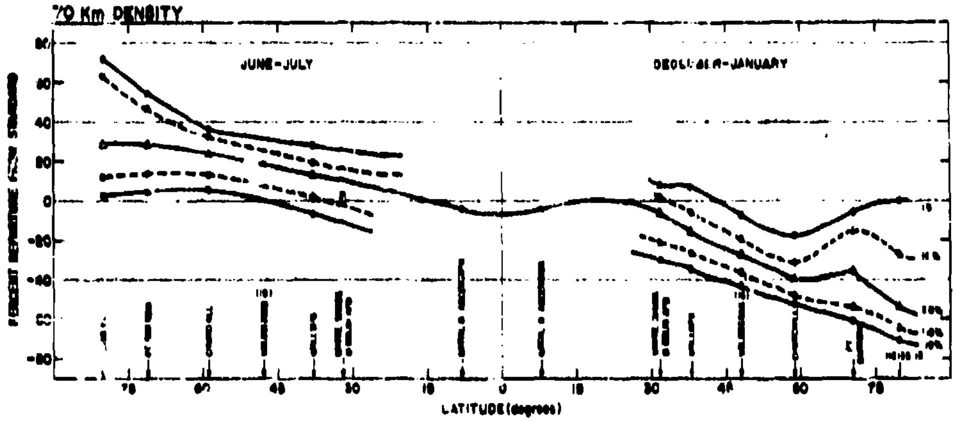
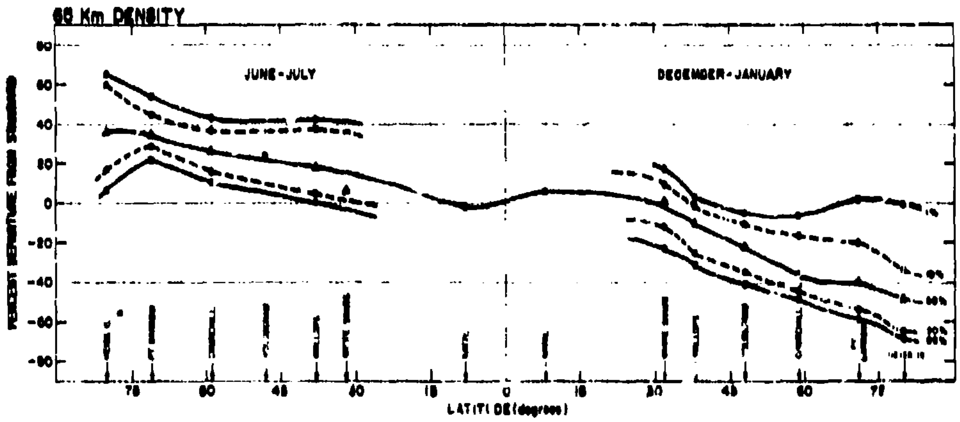


Figure 37. Median (50 Percent) and 10 and 1 Percent Extreme High and Low Density as a Function of Latitude for Altitudes of 45, 50, and 55 km. Triangles represent median values and circles seasonal mean values. (Both smoothed and unsmoothed median curves are given at 45 and 50 km. The number of available observations is given in parentheses at 50 km.)





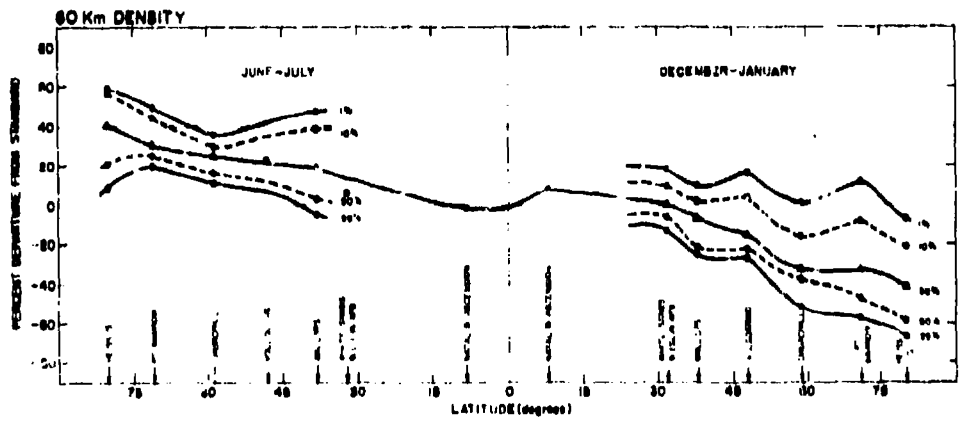


Figure 38. Median (50 Percent) and 10 and 1 Percent Extreme High and Low Density as a Function of Latitude for Altitudes of 60, 65, and 70 km. Triangles represent median values and circles mean seasonal values

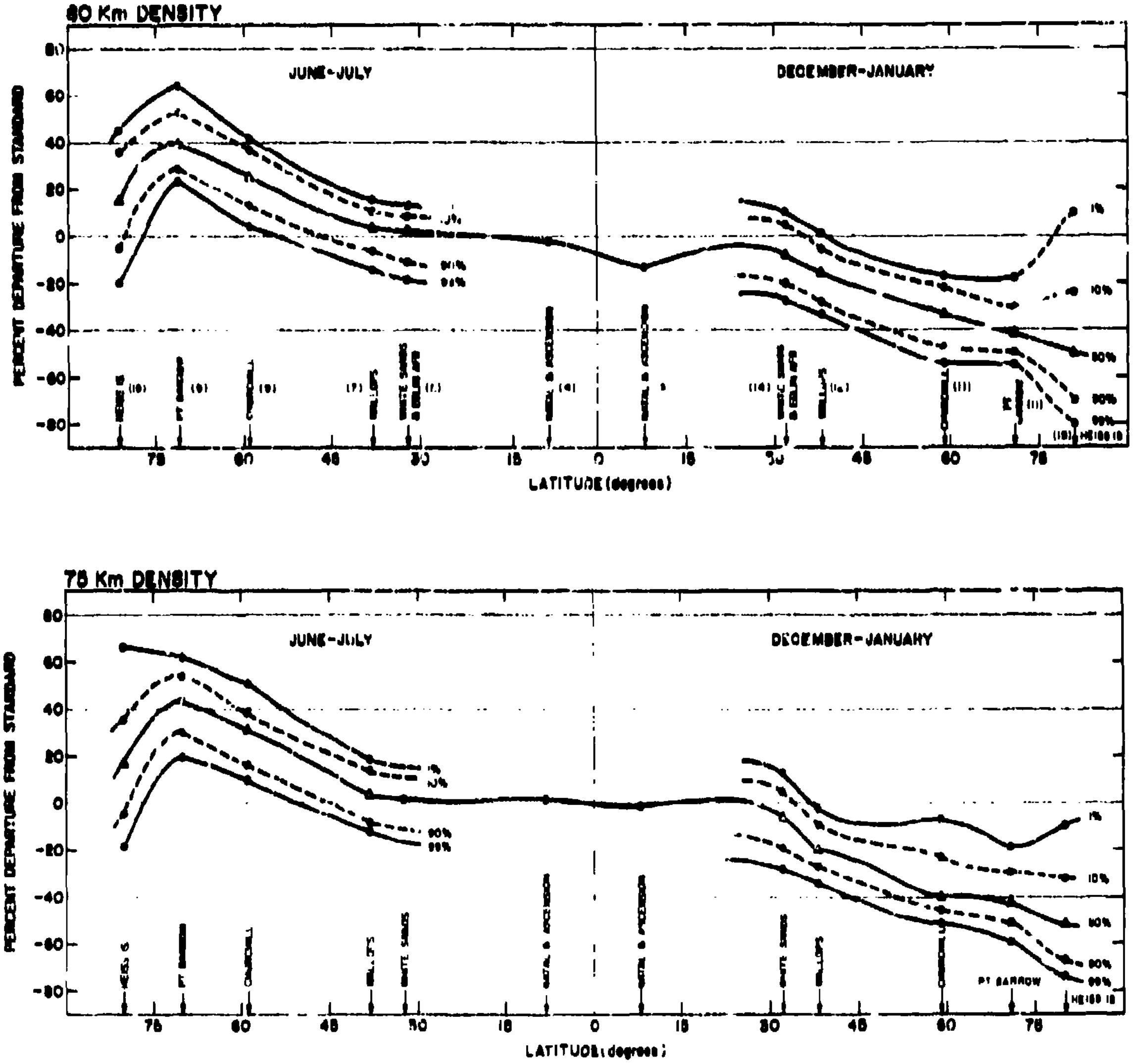


Figure 39. Median (50 Percent) and 10 and 1 Percent Extreme High and Low Density as a Function of Latitude for Altitudes of 75 and 80 km. Triangles represent median values and circles seasonal mean values. (The number of available observations is given in parentheses at 80 km.)

The estimated 1 and 10 percent extremes for the worst location and worst season (2-month period) are given in Table 87.

Table 87. High and Low Density Extremes for 30 to 80 km Geometric Altitude

Altitude (km)	High Density (kg/m^3)		Low Density (kg/m	
	1%	10%	1%	10%
30	2.10×10^{-2}	2.06×10^{-2}	$1.1[illegible] \times 10^{-2}$	1.27×10^{-2}
35	10.91×10^{-3}	10.15×10^{-3}	4.74×10^{-3}	5.60×10^{-3}
40	5.27×10^{-3}	5.03×10^{-3}	2.00×10^{-3}	$2.4[illegible] \times 10^{-3}$
45	3.79×10^{-3}	2.67×10^{-3}	0.963×10^{-3}	1.08×10^{-3}
50	14.8×10^{-4}	14.6×10^{-4}	4.62×10^{-4}	5.44×10^{-4}
55	8.64×10^{-4}	8.47×10^{-4}	2.30×10^{-4}	2.58×10^{-4}
60	4.86×10^{-4}	4.77×10^{-4}	1.01×10^{-4}	1.25×10^{-4}
65	2.75×10^{-4}	2.67×10^{-4}	0.516×10^{-4}	0.583×10^{-4}
70	15.0×10^{-5}	14.2×10^{-5}	2.54×10^{-5}	3.06×10^{-5}
75	7.20×10^{-5}	6.68×10^{-5}	1.13×10^{-5}	0.600×10^{-5}
80	3.28×10^{-5}	3.04×10^{-5}	0.400×10^{-5}	0.498×10^{-5}

The values of density above 50 km were adjusted to reflect the extremes that would occur during the most extreme two-month periods by increasing values of the frequency distributions by 2 percent in summer and decreasing them by 3 percent in winter at locations between 30 and 70°N.

Worldwide extremes (Antarctic area excluded) of density for altitudes between 30 and 80 km are considered to be conservative estimates, as they are based on observations which include random instrumentation errors. Greater confidence can be placed in the values for levels below 50 km, where the sample sizes are large and the magnitude of the random instrumentation errors has been evaluated.

Since both high and low worldwide extremes are found near the poles, additional rocket observations are needed in these regions for more refined estimates of extremes between 30 and 80 km.

2.5.1 HIGH DENSITY

High density extremes for altitudes of 30 to 80 km are provided in Table 87.

2.5.1.1 Highest Recorded

Cole did not list the highest observed temperatures for the various altitudes. Because of the small sample size, these values are generally less extreme than the estimated 1 percent extremes.

2.5.1.2 Operations

The 1 and 10 percent high density extremes are listed in Table 87.

2.5.1.3 Associated Temperatures

Cole,[78] in a separate study, provided temperatures associated with the 1 percent extreme high and low densities; these are given in Table 88. There is no unique temperature associated with an extreme density. The temperatures given are typical values (observed or estimated) that are likely to occur with the given density extremes. Values 20°C higher and lower should also be considered if conditions are critical.

Table 88. Temperatures Associated with the 1 Percent High and Low Density Extremes for 35 to 80 km Geometric Altitude

Altitude (km)	Temperature (°C)	
	With 1% High Density	With 1% Low Density
35	-17	-58
40	-5	-43
45	7	-20
50	12	-17
55	5	-20
60	-16	-24
65	-48	-47
70	-78	-63
75	-94	-68
80	-100	-62

2.5.2 LOW DENSITY

Low density extremes for altitudes of 30 to 80 km are presented in Table 87.

2.5.2.1 Lowest Recorded

See Section 2.5.1.1.

2.5.2.2 Operations

The 1 and 10 percent low density extremes are listed in Table 87.

2.5.2.3 Associated Temperatures

See Section 2.5.1.3.

2.6 Ozone Concentration

Information on atmospheric ozone concentrations for altitudes primarily below 30 km is given by Borden[74] and Kantor[75] in Section IV.1.6. Figure 40 is taken from Borden's study and is a comparison of the extreme ozone densities observed up to 30 km and the annual mean of mid-latitude densities for altitudes up to 50 km. Borden indicates that one can, using this information, subjectively estimate extreme ozone concentration for altitudes above 30 km.

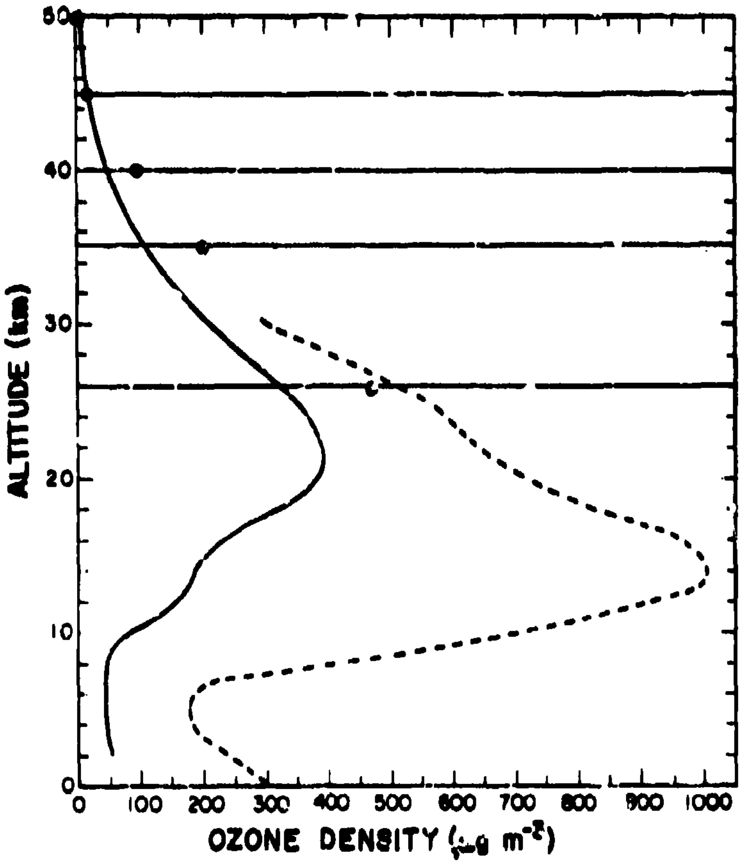


Figure 40. Comparison of Mean Annual Mid-Latitude Ozone Densities (Solid Line) with Maximum Densities Observed in AFCRL Network (Dashed Line). (Plotted points are from Randhawa's 1971 study)

The dots on Figure 40 were added to Borden's figure by the authors of this document. They represent the maximum ozone densities found by Randhawa[82] in his study of the vertical distribution of ozone between 20 and 50 km at the Panama Canal Zone using a rocket-borne ozonesonde during November 1970. These points are a further help in subjectively estimating maximum ozone densities between 30 and 50 km. It is reassuring to see points from Randhawa's data in reasonable agreement with density values determined by extrapolating Borden's curve. Ozone density extremes above 30 km will be less than those at 30 km since above this height, mean ozone density decreases, reaching a value of less than 25 $\mu g/m^3$ at 50 km.

2.7 Cosmic (High-Energy) Particles

Information on effects and extremes of cosmic rays for altitudes below 100 km has been provided by Yates.[83] He considered effects on equipment only (that is, no physiological effects). Only limits to operations were examined, since withstanding is not appropriate in the upper atmosphere. Only radiation which could damage equipment was considered. Secondary problems such as radiation ionizing the atmosphere and affecting communications were disregarded. These are more properly addressed from an ionospheric physics point of view. Finally, only the natural radiation environment was considered; values introduced by nuclear weapons were excluded.

Military equipment which is most sensitive to radiation damage are semiconductor devices (for example, transistors and diodes). These items have been known to fail in satellites in the trapped radiation (Van Allen) belts. This is the only case known to Yates where natural particulate radiation has affected the operation of equipment in this context. But the trapped radiation is not pertinent to MIL-STD-210 because it does not exist below 100 km.

Yates indicates that proton showers do not present a significant hazard because the effects are limited in time and space. Significant showers occur on the long term average of seven per year and the typical length of each is ten hours. They affect only the upper part of the atmosphere and occur only in the geomagnetic polar regions (that is, greater than about 60° geomagnetic latitude for the most part). This threat is even further degraded when one considers the limited damage to be expected even if equipment is subjected to a proton shower. No mechanical damage is anticipated. It is remotely possible that life may be endangered by the failure of a vital electronic component where the failure cannot be

82. Randhawa, J.S. (1971) The vertical distribution of ozone near the equator, J.Geophys. Res. 76, 33:8130-8142.

83. Yates, G.K. (1960) Extremes of Cosmic Radiation and Proton Showers, AFCRL (CRFC) letter of 7 Oct 1969 to AFCRL (CRF, CRE, and CREW).

corrected or circumvented by human intervention. The need for long term exposure and the shielding effects of vehicle structure and component containers operate to reduce the threat. There is no evidence that, in the presence of a proton shower, equipment would fail in a manner to endanger life as a result of radiation damage.

In the absence of proton showers, the maximum ionization occurs in the vicinity of 20 km. The rate is latitude dependent being greater closer to the geomagnetic poles. Typical maxima are 300 to 400 ion pairs/cm^3/sec/atmosphere. Balloon, rocket, and high performance aircraft at these altitudes (including the personal experience of this group), have not been known to suffer radiation damage over the many years of their operation.

Yates concluded that the natural particle radiation hazard up to 100 km is not significant enough for the purposes of MIL-STD-210. The potential hazard of artificial radiation from nuclear weapons would be more severe. Design of equipment to counter the direct and residual effects of nuclear weapons would make the hazard to natural particle radiation even more remote.

2.7.1 HIGHEST RECORDED

2.7.2 OPERATIONS

No extremes of cosmic radiation are necessary for MIL-STD-210B.

2.8 X and UV Radiation

Information on extremes of X and ultraviolet (XUV) radiation for altitudes below 100 km has been provided by Hinteregger.[84] He indicates that solar XUV fluxes in the wavelength range from about 30 Å command only limited interest for MIL-STD-210, since all of these solar fluxes except Lyman-alpha (1216 Å) are very strongly absorbed by the upper atmosphere and, consequently, do not penetrate to altitudes below 100 km with any significant intensity.

The flux of solar Lyman-alpha radiation (around 1216 Å) incident on top of the earth's atmosphere is believed to vary by no more than about a factor of two within the range from about 2.5 to 5.0 × 10^{11} photons cm^{-2} sec^{-1} (6 ± 2 erg cm^{-2} sec^{-1} in terms of energy flux density). Most of this radiation penetrates to the 100 km level, but atmospheric absorption reduces this flux most rapidly around 80 km, leaving no significant intensity to penetrate below about 70 km.

Solar X-ray fluxes of sufficiently short wavelengths (well below 30 Å) do penetrate below the 100 km level. However, the total energy flux of these harder X-rays is quite low except during relatively short times of special solar events.

84. Hinteregger, H. E. (1969) Extremes of Solar XUV, AFCRL (CRAU) letter of 26 Sep 1969 to AFCRL (CREW).

During short periods some of the harder solar X-rays may show enhancements by factors of 1000 and more, whereas most solar XUV fluxes of wavelengths above 30 Å are hardly ever enhanced to values more than twice the quiet average.

The flux of these harder X-rays in ergs cm^{-2} sec^{-1}, for various wavelength intervals, and the atmospheric absorption altitude range, is given in Table 89. These figures represent the usual solar X-ray flare, and each flare lasts between 15 min to an hour. The shorter wavelength regions die fastest.

Table 89. Energy in a Typical Solar Flare

Wavelength Region (Angstroms)	Altitude Region (kilometers)	Flux Range (ergs cm^{-2} sec^{-1} at earth distance)
0.2 to 0.6	35 to 55	3×10^{-4}
0.5 to 3.0	45 to 85	10^{-3}
2.0 to 12.0	80 to 110	10^{-1}

A really major flare, such as occurred on 23 May 1967, delivers to the atmosphere about 0.01 erg cm^{-2} sec^{-1} in the 0.2 to 0.6 Å region, and about 0.5 erg cm^{-2} sec^{-1} in the 2 to 12 Å region. These peak values lasted 15 min for both ranges, although the decay time for the short wavelength radiation was 2 hr and that for the longer wavelengths was 6 hr.

In general, during active parts of the solar cycle, several X-ray flares per day are observed. Major flares such as the 23 May 1967 type occur very infrequently, and the best "guesstimate" might be one per year.

2.8.1 HIGHEST RECORDED

This information was not provided by Hinteregger. For designing equipment whose failure would endanger life, the values given by Hinteregger for the major flare of 23 May 1967 are recommended. These are:

Wavelength (Å)	Altitude (km)	Flux (ergs/cm/sec)
0.2 to 0.6	35 to 55	0.01
2.0 to 12.0	80 to 110	0.5

2.8.2 OPERATIONS

Extremes of hard (damaging) solar X and UV radiation cannot be provided as a value exceeded 1 percent of the time of the worst month over the worst area. That there is a worst month and area is quite questionable. There is an 11-year

cycle of solar flare activity. During the years of maximum activity, flares occur about once every 2 or 3 hr. Typical energies are given in Table 89. Design for operations when a risk of only 1 percent is approximated should be greater than values given in Table 89 but less than those given in Section 2.8.1.

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Appendix A

Revision Chronology

The decision to revise MIL-STD-210A was reached through a series of tri-service meetings initiated in 1967 by the Design Climatology Branch in response to a memorandum from the Office of the Assistant Secretary of Defense.[85,*] It established a tri-service study group (DOD, Engineering Practice Study, Project MISC-0440) to make recommendations concerning MIL-STD-210A. In this process, a questionnaire on the utility of and necessity for revision of MIL-STD-210A was sent out independently by each of the three departments to MIL-STD-210A users and/or potential users.

Each Department was invited to send three voting representatives to the initial 1967 meeting: a staff official with knowledge of his Department's overall environmental goals and calculated risk design philosophy; a systems oriented staff engineer with a background in the application of environmental standards to design (and testing) problems; and an environmental scientist with background in the presentation of environmental "inputs" for military design criteria.

*References given in this Appendix are not listed at the end of the Appendix but are included in the Reference section of the main body of this report.

85. Office of the Assistant Secretary of Defense (1967) Memorandum to the Army, Navy and Air Force, on Military Standard MIL-STD-210A, Climatic Extremes for Military Equipment – Engineering Practice Study Project MISC-0440, 19 July 1967, OASD, Documentation Management Division, Directorate for Technical Data and Standardization Policy, Washington, D. C.

A.1. JULY 1967 MEETING

This meeting resulted in the following decisions and conclusions (Sissenwine and Gringorten):[86]

1. Retain or cancel MIL-STD-210A?

This first question was posed to each of the participants. No participant recommended cancellation. All agreed with the Chairman's (N. Sissenwine) summarization of the discussion that MIL-STD-210A should be retained. Comments and discussion included:

a. There is a need for MIL-STD-210A. Its cancellation would be followed by serious repercussions, but its weaknesses must be remedied.

b. There should be a clearer statement or statements on applications of the document, and it should outline the procedure for filing exceptions and departures from the standards.

c. We cannot cancel the document and have users seek individual guidance from scientists, since conflicting answers will be obtained. In fact, there has been difficulty in getting scientists to agree on numbers.

d. A fairly complete revision of the document is needed since more elements describing the natural environment are needed.

e. MIL-STD-210A needs improvement in its language of communication; the original Quartermaster Report No. 146 was easier to read and use.

f. Though all Departments have used MIL-STD-210A, some offices in them concerned with extremes of the environment have not heard of it or taken it off the shelf, even for reference.

g. It should be limited to the unmodified natural environment (not include tents, box cars, etc.), and examples should illustrate the difference between natural and the induced environments.

h. Examples should also show how to use the document, and everything possible should be done in the writing or composition of the revision to avoid misuse.

i. MIL-STD-210A is necessary as a basis for environmental tests such as described in MIL-STD-810.

j. The document should be easy to use and easy to reference.

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86. Sissenwine, N., and Gringorten, I. (1967) Minutes of DoD Engineering Practice Study, Project MISC 0440 on Proposed Revision of MIL-STD-210A, Climatic Extremes for Military Equipment, 24-25 July 1967, AFCRL, Design Climatology Branch.

2. Mandatory use and exceptions:

It was agreed that the document should return to the original intent, to provide standard climatic extremes that are mandatory* goals in design and serve as the basis for environmental tests. It is recognized that there will be instances when the mandatory goals are not reasonable. In such cases of exception, justification must be provided.** Justification might be the fact that the equipment is intended for limited use, or will be protected against extreme environments. Another justification might be the fact that, to meet the mandatory standard the cost and bulk of the equipment would make it impractical, and therefore a greater risk factor is in order. (Equipment being designed for operation at a specific location will not require that exceptions be justified, since such items do not fall under the purview of MIL-STD-210A.)

The consensus was that the Department responsible for the design and development of an item should be responsible for granting of exceptions. Hopefully there will be sufficient difficulty in justifying exceptions that equipments of any Department will satisfy the operational requirements of the other Departments when required by the non-developer.

In discussion of the mandatory aspects of the document, it was recognized that some environmental conditions may not be amenable to succinct description of extremes. In such cases the Standard will so state and describe the extremes in general terms, and give references for further information or to other criteria.

3. Minor changes versus a major revision:

There was general agreement that the changes should not be minor. There should be a complete revision, probably designated as MIL-STD-210B. The purpose should be clarified.

The suggested major changes were:

a. Indicate a requirement for obtaining exceptions to the use of the extremes in the standard for standardized equipment.

b. Include for information† purposes, the greatest extremes on record.

c. Include a set of extreme values with likelihood of occurrence greater than the mandatory extremes for guidance when exceptions for the mandatory extremes are being sought.

*During the preparation of the final version of MIL-STD-210B, it was learned that the word "mandatory" could not be categorically used in specifying extremes for each element. Specification of them, in itself, establishes that they are mandatory.

**The whole matter of exception and justification was deleted in the final version of MIL-STD-210B because it was learned (during the coordination cycle) that such matters do not fall within the purview of a military standard; rather, these matters belong in the regulations or implementation documents of each service.

†Such extremes are also needed for another purpose discussed later in this Appendix.

d. Include additional climatic elements.

e. The two types of extremes will be for "operations" and "withstanding", not "operations" and "short term storage and transit", as in MIL-STD-210A. Extremes mandatory for actual operations will usually differ from those which equipment must withstand without irreversible damage while in unsheltered standby or in primitive storage (or transit) in the field.

f. More examples of the application of the document should be provided.

4. Definition of "Climatic Extremes":

It must be made clear that MIL-STD-210B deals only with the natural environment, not with the environment induced by operations of the equipment. Also it was decided that the induced environments of storage and transit should no longer be included, since such extremes, say 160°F for the air in a closed desert storage, have been erroneously applied to equipment. Instead, storage extremes for design must be ascertained by engineers for each item by consideration of energy transfer while undergoing crude storage and transit under the worldwide extremes of the natural environment. These worldwide extremes must be included in realistic cycles (or durations) with other influencing environmental parameters. These cycles (or durations) will also serve as realistic tests for simulating extreme environments.

5. Kinds of extremes to be presented:

There was surprisingly good agreement on the types of extremes which should be presented. Three general kinds of figures will appear in the document: (1) mandatory extremes; (2) greatest extreme on record; and (3) lesser (more possible) extremes (for consideration in design problem areas).

a. For operational purposes, the mandatory extreme will be the value that is attained 1 percent* of the time in the most extreme month in the most extreme area.

b. For withstanding without irreversible damage, the mandatory figures will be provided for 1 percent** risk or occurrence in 2, 5, 10, and 25 years. The value selected for a specific equipment will be related to intended field life of the equipment (later termed expected duration of exposure, EDE). Mandatory figures will be given for the most extreme area but only annual extremes will be important in arriving at those values since emphasis is on withstanding more than 1 year of expected exposure.

*For cold surface temperatures this was later changed to 20 percent; for precipitation, it was changed to 0.5 percent. These changes will be discussed later in this Appendix.

**This percent was changed at a subsequent meeting. The change will be discussed in this Appendix.

For guidance when the mandatory extreme presents an unsurmountable design problem or renders the cost of the item prohibitive, the value that is exceeded five percent* of the time and the 5 percent* risk in 2, 5, 10, and 25 years will also be included. To use the "lesser" extreme in the design of equipment, the procedure to obtain an exception must be followed. It is conceivable that relaxation of the 1 percent risk to 2, 3, or 4 percent rather than 5 percent can only be justified. These values must be obtained from environmental scientists during processing of the exception.

In connection with the "worst" area, the issue of formulating extremes for locations of little military importance that suffer unusual extremes of weather was raised. Wind and icing on the peak of Mt. Washington in winter were given as illustration. It was decided that data used should be representative of the worst geographic area, not an anomalous location in it.

6. Partitioning of MIL-STD-210B:

It was decided that to be most applicable to operational categories of military equipment, climatic extremes should be separated into three parts, applicable to the operational environment of each Department:

"Land" (replaced Ground Outdoors in MIL-STD-210A);**

"Sea Surface and Coastal" (replaces Shipboard);†

"Air" (replaces Atmospheric Extremes).‡

These three parts will need further definition such as height of terrain for "Land", depth inland for "Sea Surface and Coastal", and altitude for "Air". It is anticipated that the Department most intimately concerned for the part, will establish these limits. Suggestions of "Space" and "Underwater" parts were not accepted since these are not usually classified under climate.

7. Supporting evidence:

Since these will be mandatory extremes, should the document include documentary support of the values?

It was decided that detailed support should not appear in MIL-STD-210B, but the preparing agency or agencies will keep supporting studies and data on file in case of challenge, and for later reference.

8. Durations and cycles:

Since climatic extremes generally are limited to rather short periods of time (extreme cold), or appear in diurnal cycles (extreme heat), and since such

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*This percent was changed at a subsequent meeting. The change will be discussed later in this Appendix.

**Renamed "Ground Environment".

†Renamed "Naval Surface and Air Environment".

‡Renamed "Worldwide Air Environment".

time factors will influence the impact of the extreme, providing only the 1 percent extreme is often not enough. It is necessary, especially in the case of high temperature and humidity, to give a cycle of values throughout a 24-hr period; for low temperature, it is necessary to give the duration. Sunshine, wind, etc. must also be included in such descriptions. Records will be searched for typical situations when mandatory extremes were attained. Diurnal cycles and durations will be based on such typical conditions. Realistic tests can thus be developed and designers can adequately consider the transitory nature of extremes in order to not over-design. Special care must be given to wind gust durations, since the size of an item determines the minimum gust size to which it is most sensitive.

9. Climatic elements to be presented:

Each part will have a set of climatic elements. Many elements will be common to all parts, but some elements may appear in one or two parts only.

For the "land" portion of the study, the following climatic elements were recommended:

a. High and low temperature
b. High humidity
c. High wind and gust spectrum (also vertical profile in boundary layer)
d. Blowing sand and dust.
e. Low pressure
f. Low density
g. Precipitation (rain, hail, snow, ice accretion)
h. Atmospheric electric field strength
i. Aerosols (including pollutants)
j. Ozone
k. Horizontal visibility.

The same elements were generally recommended for the "sea surface and coastal" portion with the addition of:

a. Salt spray/fallout
b. Sea state (breakers, swells)
c. Salinity
d. Water temperature

For the air section, the following elements were recommended:

a. Temperature vs altitude
b. Humidity vs altitude
c. Liquid and solid aerosols (in clear air and in clouds in the troposphere)
d. Wind profiles (related to forces on vertically rising missiles)
e. Winds (applicable to aircraft cruise problems)
f. Turbulence and undulance

g. Ozone vs altitude

h. Pressure vs altitude

i. Density vs altitude

j. Hail vs altitude

k. Icing

l. Harmful radiation (ultraviolet, X-ray, cosmic rays, proton showers, etc.)

m. Atmospheric electricity gradients

n. Ionization

o. Dissociated gases (atomic oxygen, atomic nitrogen, etc.)

p. Ceiling (cloud base) and visibility.

The altitude to which values for the upper air are to extend was not fixed. Military aerospace activities have requested detailed environmental data to at least 100 km; therefore extremes to at least this altitude should be the goal. It may be feasible to estimate some extremes up to 200 km. The ultimate altitude will depend on future requests for this kind of information.

10. Units:

Units will be in both English and metric, except for complex and/or extensive tables. These will be in metric units if it is not feasible to give both units.

11. Division of study effort:

Responsibility for studies to support recommendations for new extremes which will be used in the revised MIL-STD-210 should be shared by the Departments, with each Department holding prime responsibility for the environment under its general cognizance. The chairman suggested the following division of work:

Land:	Army	(Natick Labs)
Sea Surface and Coastal:	Navy	(Research facility to be designated)
Air:	Air Force	(Cambridge Research Laboratories)

12. Relation to other environmental standards:

Revision of MIL-STD-210 should be followed by revisions of MIL-STDs for testing that are dependent on natural environmental extremes. This is especially true for MIL-STD-810, with which several of the participants of this meeting have been associated. Another standard affected is MIL-STD-202 for electronic components.

This terminates important decisions and conclusions reached at the July 1967 meeting.

A.2. FINAL REPORT, ENGINEERING STUDY PROJECT -MISC 0440

Following the 1967 meeting, there was a further exchange of tri-service views through several secondary meetings, written correspondence, and telephone calls. This led to a final report containing coordinated recommendations[87] which formally answered the memorandum from the Office of the Assistant Secretary of Defense.[85] The conclusions and recommendations of this report were:

1. MIL-STD-210A should be completely revised and designated MIL-STD-210B. It should have as its purpose:

"To establish mandatory requirements to be used as a basis for design of military materiel which must withstand and operate in the worldwide climatic extremes of the natural environment. These requirements are not necessarily testing criteria but will serve as a basis for testing. This document does not apply in design of materiel to be used only in specific locations.

"When these requirements are impractical for a specific item of materiel, an exception or deviation must be identified and justified. This justification will include engineering studies showing savings involved in the acceptance of alternative limiting extremes, and environmental studies showing the risk incurred by the acceptance of these alternatives."

2. Only climatic extremes of the natural environment will be provided. Extreme conditions induced in the materiel in "short-term storage and transit", a classification used in the current MIL-STD-210A, should not be specified qualitatively in MIL-STD-210B, since these are variables dependent upon the physical characteristics of the materiel and the conditions of exposure or storage. However, equipment must be designed to both operate in, and withstand, the conditions induced in crude storage and transit that is consequent to the natural environmental extremes specified in MIL-STD-210B. These induced extremes must be determined by the responsible designers for each item from theoretical considerations and most applicable empirical data.

3. Background documents for revised worldwide extremes are to be prepared for "land", "sea-surface and coastal", and "air" by the Army, Navy, and Air Force, respectively. Further development into climatic regimes will be omitted or delayed until a later date, or left to individual Departments for development in supporting documents. First drafts or preliminary copies should be made available to all participants, and additional meetings will be scheduled to review these, as required. All services can offer suggestions and scientific material for each part.

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87. Anstey, R., Sissenwine, N., and Ott, H. (1969) Final Report Engineering Practice Study Project - MISC - 0440 Revision of MIL-STD-210A - Climatic Extremes for Military Equipment (8 Jan 69) on file at AFCRL, Design Climatology Branch.

4. The limits, to be established for each climatic element, should be developed from actual climate for the most severe geographic area in which military materiel realistically might be installed, operated, or stored.

5. Limits should be given for only two conditions of exposure: "operations" and "withstanding exposure to the elements without irreversible damage during the planned life in the field". The latter is, hereafter, termed "withstanding". For operations, the established limits should be those of a given calculated risk of occurrence in the most severe month (or season) in the most extreme location. For withstanding, the established limits should be those of given risk of occurrence in a specified number of years, the planned life* of the item. The latter will be more severe extremes.

6. To avoid misuse, a clear statement, or statements, on application of the document should be included and prominently located in MIL-STD-210B.

7. A set of less severe values, with greater likelihood of occurrence than the mandatory limits, should be presented in MIL-STD-210B to provide guidance when requesting waivers. If possible, a statement in MIL-STD-210B should be provided to outline the procedure for identifying, justifying, and filing waivers.

A.3. THE JANUARY 1969 MEETING

Another tri-service meeting was held in January 1969 to review the above-mentioned report. Also reconsidered were the geographic area to which MIL-STD-210B should apply, the percent risk and design philosophy that should be used in calculating extremes, and the climatic elements to be considered. The following discussion and decisions resulted:[51]

1. Reconsideration of geographic area:

Staff guidance on the geographic area to be considered for worldwide extremes was reviewed. The philosophy, design for the coldest and hottest area on the earth's surface, with exception of the Antarctic continent, at a 1 percent risk during the most severe month, agreed to at the July 1967 meeting, but without adequate staff guidance, had been questioned since it leads to temperatures of -70°F or less as the required extreme for all military materiel developed for worldwide usage. There was no experience to support the contention that military operations would be conducted at such extremes and that military equipment would be exposed to these conditions often enough so as to require that all "worldwide" equipment have these extremes as design criteria. Army representatives who checked into the geographical area which should be considered in design of materiel

*This was later changed to expected duration of exposure, EDE.

for future military operations by the Army, reiterated that no area can be excluded except the Antarctic. Analogous Navy and Air Force guidance had not been provided.

In an attempt to alleviate unrealistic temperature extremes in design, it was tentatively decided to adopt a design philosophy which accepts a 10 percent risk (10 percent of the time) in the most extreme location for each element* during the severest month, rather than 1 percent. The Air Force representatives indicated that they would ask that this problem be given careful consideration by Air Staff. Hopefully, the Navy would also be able to bring Staff thought to bear on this problem.

In July 1967 it was agreed to include for information purposes a set of values which have a higher probability than the mandatory extremes. These were not to be used unless special permission is granted, as discussed in the second paragraph of the purpose of MIL-STD-210B. It was tentatively agreed to establish these lesser extremes at the 20 percent probable value for the most severe locations and months.

2. Reconsideration of design philosophy:

a. Operations

(1) High temperature cycles should be provided in which the peak temperature has a 10 percent** probability of occurrence. It should be depicted in a synthetic 24-hr cycle (including concurrent solar radiation) developed from hourly records obtained on days when the 10 percent probable values are attained.

(2) For climatic elements in which exposure time required to reach equilibrium is important and the diurnal cycle is not marked (very low temperatures during polar night) the 10 percent values should be given for a family of durations, since the 10 percent extreme would normally occur for only an hour or two. For low temperature, durations up to 72 hr would be shown.

(3) Certain problems of calculated risk involving human safety were discussed. Typical is the problem of landing aircraft during heavy precipitation with the aid of GCA radar. Considerable difficulty had been encountered over Vietnam. Although it may be acceptable not to be able to operate a weapon or other item of material for 10 percent of the time in a most severe location and month, this may be a far greater risk than is acceptable for problems in which life, limb, and expensive equipment, such as aircraft, are at stake. Perhaps special sets of extremes are required for personnel hazard with only a fractional

*Use of a 10 percent risk for all climatic elements was changed at a later meeting.

**Later changed to 1 percent.

percent calculated risk of the climatic element that is associated with such problems. They would fall between all time record extremes and the 10 percent values which are standard for materiel. It was agreed that this problem should be brought to the attention of the Air Staff for guidance.

b. Withstanding

For "withstanding" it was agreed to provide the 10 percent probable values for a planned life of 2, 5, 10, or 25 years as the required standard for materiel instead of the 1 percent values decided upon in July 1967. The lesser extremes would be those with 20 percent probability for the same planned life.

3. Reconsideration of climatic elements:

a. The material on climatic elements in the Minutes of the July 1967 meeting[86] was reviewed. Time was available to go over the "land" section only. It was agreed that the elements for "sea surface and coastal" and "air" would be treated in an analogous manner. Establishing the boundary between "sea surface and coastal" and "land" sections was discussed. No firm decision was reached, but it seemed that the landward extent of "sea surface and coastal" could be limited to seaports. The boundary between "land" and "air" was also discussed and it seemed that some arbitrary height in the friction layer, say 100 m, would be acceptable.

(1) Thermal

These extremes should be given the highest priority. The high temperature cycle should show concurrent relative humidity and wind speed as well as solar radiation. The low temperature cycle should show the concurrent range of relative humidities and wind speed. By presenting humidities with these temperature extremes there would be no need for establishing low humidity extremes as a separate standard.

(2) Humidity (high)

This set of extremes should have second priority. Typical 24-hr cycles of dewpoint and temperature for the (1) jungle, (2) an open field in the moist tropics, and (3) a hot coastal desert, on days when the dewpoint is that which is exceeded only 10 percent* of the time of the severest month, should be provided. Solar radiation and wind accompanying these humidities should be provided.

(3) Wind

Development of wind extremes should have third priority. Extremes for both "operation" and "withstanding" should be provided in the form of the steady wind (averaged over 1 min) and accompanying gusts which are winds

*This probability was changed at a later date.

averaged over a spectrum of shorter durations such as 45, 30, 20, 10, 5 sec or less. These gusts should be the values that are probable with the steady wind. The wind values should be for a standard height above the surface which must be determined. Provisions for extrapolation to other heights must be provided.

(4) Sand and Dust

The requirement for these extremes should be given no priority. It is understood that the Army has some available studies and that the Navy will provide some additional data which can be packaged into the best estimate of extreme conditions of wind and dust. Sophisticated probability treatment cannot be applied in this case.

(5) Pressure

For the low extreme, pressure in the worst climatic zone corresponding to the maximum geometric altitude at which land equipment is expected to operate should be provided. Altitudes of 15,000 ft were indicated by Army representatives as the probable value. No maximum pressure is required. Determining this extreme should require only minimum effort and requires no priority.

(6) Density

Extremes of density at the surface for geometric altitudes up to the maximum at which land operations are anticipated should be provided. These would be quite pertinent to helicopter take-off and hovering. No priority is considered applicable.

(7) Precipitation

This element is to be given fourth priority. Instantaneous rainfall rates are to be provided for both operation and withstanding. Drop size distribution is to be included. Hail values to be provided are applicable to "withstanding" only. Rate of snowfall (linear depth and density) is to be provided for operations, snow load for "withstanding". Some best estimates of extreme ice accretion should be included, but it is recognized that data cannot be provided on a probability basis.

(8) Atmospheric Electricity Field Strength

This element is not be included in the "land" section at this time.

(9) Aerosols

No priority is to be given this element. Scientific estimates of extremes from appropriate authorities have been suggested.

(10) Atmospheric Pollutants

Same as (9).

(11) Ozone

No extremes will be given for land. Estimates of extremes will be provided by altitude in the "air" part.

(12) Horizontal Visibility

It is believed that a realistic value of the visibility which is exceeded 90 percent of the time (10 percent risk) can be readily obtained from the "Revised Uniform Summaries of Surface Weather Observations", which are available on a worldwide basis for the station with the poorest visibility.

4. Requirements for professional environmental guidance:

MIL-STD-210B should contain statements in the introductory material which require that the management offices that are responsible for the development of new materiel review application of MIL-STD-210B with appropriate environmental scientists in their military Department. Though there was complete agreement in principle with the desirability that this be required, details for implementation of this could not be specified at the meeting.

A.4. EVENTS BETWEEN JANUARY AND JUNE 1969

Following the January 1969 meeting, the Staff Director, Standardization and Specification Management Division, Directorate for Technical Data, Standardization Policy and Quality Assurance, Office of Assistant Secretary of Defense, OASD (I & L) established on 31 January 1969, Standardization Project MISC-0597 for the purpose of revising MIL-STD-210A, Climatic Extremes for Military Equipment. A Task Group method involving all departments in the DoD was recommended. The revision was to follow that outlined in the final report to OASD of engineering practice study project MISC-0440, 8 January 1969.

As indicated at the January 1969 meeting, a need existed for high level guidance on the probability levels of extremes that are acceptable as risk. Accordingly, in April 1969 the Office of the Assistant Secretary of Defense requested such guidance in a memorandum to the Special Assistant for Environmental Services, Joint Chiefs of Staff.

A.5. JUNE 1969 MEETING

A tri-service meeting was held in June of 1969 to review progress of the JCS in providing guidance, report on progress in the three Departments on background studies required to arrive at extremes, discuss general problems, and to plan future actions leading to MIL-STD-210B.[88] At this meeting, the following purpose for MIL-STD-210B was drafted and agreed upon:

88. Design Climatology Branch (1969) Minutes of DoD Standardization Project MISC-0597 Meeting on Proposed MIL-STD-210B, Climatic Extremes for Military Equipment, 17-18 June 1969, AFCRL.

Purpose: This standard provides sets of probable extreme climatic conditions for land, sea, and air in which military materiel (including equipment) may be required to operate. It also provides separate sets (land, sea, and air) of probable extreme climatic conditions which materiel exposed to nature may be required to withstand without damage when in place or stored without shelter. These extremes are those of nature impinging on the materiel and its containers. The responses of the materiel to these extremes are beyond the scope of this document.

This standard establishes for the Department of Defense uniform climatic conditions which are mandatory goals in developing design criteria for military material intended for worldwide usage. It does not apply in design of materiel to be used only in specific locations. These climatic conditions are also to serve as a basis for environmental testing of materiel which is designed to meet this standard.

Employment of this standard must be formally coordinated with appropriate environmental scientists within the Department that is responsible for design and development of each item of materiel in order to guard against misuse and to insure that all professional guidance available is obtained.

When these climatic extremes are impractical for a specific item, an exception or deviation must be identified and justified to the authority specified by each Department. This justification will include: (1) engineering studies prepared within the developing agency, showing savings involved in the acceptance of alternative limiting extremes, and (2) environmental studies prepared by the appropriate environmental organization in the responsible Department showing the risk incurred by the acceptance of these alternatives.

Also at this meeting the needs of the various types of humidity extremes were reviewed. It was agreed that there should be cycles (humidity and associated temperature) for each of five humidity extremes, listed below, since the type of extreme that is detrimental to one type of materiel is not necessarily the most severe humidity extreme for all materiel:

1. Coastal desert cycle in which the highest absolute humidity is incorporated;
2. Hot desert cycle in which the lowest relative humidities are encountered;
3. Wet tropical jungle cycle in which air is always at or near saturation;
4. Wet tropical open field cycle;
5. Low absolute humidity cycle (or duration) associated with cold temperature extreme.

It was agreed that diurnal cycles would be needed only for high temperature and high humidity. Duration would be required for low temperature and low humidity; wind and gust limits should be single values; and precipitation would be

instantaneous rates for operations. It was also noted that the part on "air" would include only extremes for operations, since withstanding is not considered a problem of the upper air.

A.6. GUIDANCE FROM THE JOINT CHIEFS OF STAFF

In August 1969, the JCS in a Memorandum for the Secretary of Defense (Joint Chiefs of Staff, 1969) provided the views to OASD (I & L) in response to a request of the tri-service study group. The guidance on the percent risk to be employed for the different elements was definite but limited because it was based on only three studies—surface temperature, rainfall rate, and wind extremes—provided on short notice to the JCS by AFCRL's Design Climatology Branch. In the memorandum, the JCS presented answers to four questions posed to them by the study group. In preparing these answers, the JCS had the following understanding of the proposed use of the revised military standard:

1. The purpose is to establish mandatory requirements to be used as a basis for the design of military equipment which must withstand and operate in the world-wide climatic extremes of the natural environment.

2. The standard does not apply to the design of materiel to be used only in specific locations or only in specific climatic regimes (for example, arctic, desert, or tropics).

3. The standard will prescribe procedures to grant exceptions or deviations from the criteria in those cases in which the requirements are impractical for specific items of equipment.

The percent risk recommended by the JCS was based upon a recognition of the practical limits of the current state of the art to produce materiel which can operate in and withstand the absolute, observed climatic extremes. The Joint Chiefs of Staff also recommended that this standard be reviewed periodically to relate future technological developments with higher goals of reliability.

The questions posed to the JCS and their answers were:

1. Question

"Over what geographical areas of the world should standardized military materiel be designed for military operations (a) on land, (b) on the sea, and (c) in the air, or conversely, what areas can be excluded?"

View

No areas of the sea and air can be excluded. Small, isolated anomalous topographic features, such as high mountain tops, as well as the land and ice shelf areas south of 60°S latitude, can be excluded from consideration for this purpose.

These exclusions would not apply to some categories of standardized materiel, such as communications equipment, which frequently are employed on anomalous topographic features.

2. Question

"What calculated risk is acceptable in establishing mandatory climatic extremes for operations of materiel in severest locations for each element within the geographical area included in response to question 1?"

View

Based upon current, practical, design limitations, and/or state of the art, the following percentages of inoperability on land surfaces during the most severe month in the severest locations are acceptable:

Cold:	20 percent
Heat:	1 percent
Steady Wind:	1 percent
Rainfall:	0.5 percent

The values specified for "steady wind" and for "rainfall" do not apply to communications and electronics equipment. These values will be determined on a case-by-case basis, depending upon operational requirements and systems technical standards. Due to a lack of sufficient climatological data to relate risks to geographical areas, no risk values are given for the sea and air or for other climatic elements on the land surface.

3. Question

"What calculated risk is acceptable to establish (for equipment that is permanently exposed or in long-period standby) mandatory extremes for "withstanding" without irreversible damage, during exposure in the severest geographical locations specified in response to question 1?"

View

Based upon current, practical, design limitations, and/or state of the art, the following risks of the occurrence or irreversible damage on land surface are acceptable:

Cold:	10 percent
Heat:	10 percent
Steady Wind:	10 percent
Rainfall:	10 percent

Due to a lack of sufficient climatological data to relate risks to geographical areas, no risk values are given for the sea and air, or for other climatic elements on the land surface.

4. Question

"The final question involves hazards to personnel because of design limitations of equipment and associated calculated risks. While 10 percent risk may be acceptable with respect to a piece of equipment, say a gun, during the coldest month of the year in the severest geographical locations, will so great a risk factor be acceptable to such equipment as GCA radar that must bring an aircraft safely home?"

View

When the inoperability of an item of equipment directly endangers human life, the design criteria for climatic extremes should be established so as to result in a percentage of inoperability which is as close to zero as is practically possible. The climatic design requirements should be determined on a case-by-case basis to ensure the achievement of maximum practical reliability.

A.7. OCTOBER 1969 MEETING

This meeting[57] was held to review views provided by the JCS to OASD (I & L) on acceptable risk philosophy and geographical areas provided as guidance in arriving at climatic extremes, report on progress in the three departments on developing background studies required to arrive at extremes, to discuss general problems that have arisen, and to plan future actions leading to MIL-STD-210B.

The following discussions/decisions resulted from this meeting:

1. Review of guidance on geographical areas and calculated risk:

Chairman Sissenwine offered a comment that the guidance implied considerable flexibility. For example, a calculated risk of 1 percent for operations was recommended for the hot extreme and 20 percent (worst area, worst month) for the cold extreme. The cold extreme value, required if a 1 percent risk across the board had been decided upon, would be far colder than attainable for the operation of much military equipment in the foreseeable future. Further evidence of flexibility is indicated by the still lesser risk, 0.5 percent for operations, specified for rainfall. The guidance provided was limited to only a few of the weather elements over land areas because questions asked of the JCS used examples for this problem area. Hopefully, JCS approach in these responses could be generalized in arriving at solutions to the many other questions that could not be covered in this guidance.

There were several specific actions suggested which should be based upon the guidance. Those to which the conferees agreed were:

a. In recognition of the views of the JCS on geographic areas requiring consideration, the following statement should be added to the Purpose of

MIL-STD-210B. Certain standardized material such as communications equipment are designed specifically for employment on exposed high mountain tops or other anomalous topographic features where extremes are likely to exceed the standardized values for land "operations" and "withstanding without irreversible damage". Special sets of extremes for such equipment must be obtained through conference with appropriate environmental scientists within the Department responsible for their design and development.

b. The JCS indicated a definite intent that the calculated risk for operations be applied to the worst season or worst month. In the working paper of 3 June 1969, however, prepared for JCS's consideration of rainfall, the probability distribution of instantaneous rates were applied to the whole year. Consequently, the rate of 0.40 in./hr, corresponding to 0.5 percent risk, is considerably less than it would be in the rainiest month in a tropical monsoon area where this element is most critical. The value of 0.40 in./hr is not particularly demanding as a design extreme for much military equipment sensitive to rain. Yet, if it were the threshold value for operation, equipment would be inoperable for a greater amount of time than 0.5 percent during the rainy season. It was agreed to increase the rainfall rate value to 0.5 percent for the rainiest month. It was assumed this would be completely acceptable to SAES. Also, it was decided that the instantaneous rates would be more meaningful if provided in mm/min rather than in./hr.

c. In response to the guidance provided for question 4, it was decided to include a set of either actually observed or estimated absolute extremes for all of the meteorological elements and to add a statement such as the following to the introduction of MIL-STD-210B: If a weather extreme encountered during operation could cause certain equipment to fail and result in the endangerment of the life of the operators or other personnel, the extreme for design should be established so as to result in a percentage of inoperability which is as close to zero as is possible. This document, therefore, also indicates recorded or estimated extremes which should be considered as goals for design of such equipment. As an example, consider radar used to guide aircraft on the final approach to landing. These must be able to penetrate even greater extremes of rainfall than the rate required for operation of other equipment since failure of this radar during such a rainfall situation could cause destruction of the aircraft and loss of crew and occupants.

2. On future plans

a. After receipt of all supporting studies, AFCRL (LKI) will prepare a draft MIL-STD-210B. The format of MIL-STD-210A will be followed, wherever possible. A table will be provided in which extremes for both "land" and "sea surface and coastal" portions are included, but the upper air extremes cannot be

shown on the same type of table since there will be extremes for each altitude level. It may be conceivable to show the most extreme value and its altitude on such a chart. Such details will have to be worked out.

b. When the first draft has been prepared, it will be circulated to all the working level participants. A meeting will then be held about a month after distribution for informal review.

c. The revised draft will be furnished to OASD (I&L) through appropriate channels for formal coordination.

A.8. JULY 1972 MEETING

By June 1972 essentially all background studies had been completed and a first draft MIL-STD-210B plus a first draft of the synopsis of the background studies had been prepared. These documents were sent to the Task Group for their review and a meeting was called to discuss these documents. The meeting took place on 17-19 July 1972 and was reported on by Sissenwine.[89] The following decisions were reached at this meeting:

1. With regard to the "background document":

a. The title of the background document will be Synopsis of Background Material for MIL-STD-210B.

b. MIL-STD-210B will make reference only to this background report for supporting documentation. In turn, it will provide detailed reference to studies prepared specifically for MIL-STD-210B and other material used.

c. A list of Task Group participants and acknowledgments for background studies especially prepared for MIL-STD-210B will be provided near the front of the background document.

2. With regard to the draft MIL-STD-210B:

a. The duration related to withstanding for 2, 5, 10, and 25 years was changed from "equipment planned lifetime" to "expected duration of field exposure". This expected duration can vary with the element.

b. Information which emphasizes that level-by-level extremes provided in the section on "air" cannot be considered as vertical profiles will be included. They are envelopes of extremes which occur at various locations at different times. For engineering problems requiring internally consistent vertical profiles of atmospheric conditions typical of extreme climates (analogous to the polar and tropical

89. Sissenwine, N. (1972b) Minutes of DoD Standardization Project MISC-0597 on Proposed MIL-STD-210B, Climatic Extremes for Military Equipment, 17-19 July 1972, AFCRL Design Climatology Branch.

atmospheres in MIL-STD-210A), use of various representations in "U.S. Standard Atmosphere Supplements",[5] will be recommended. (Polar and tropical atmospheres are average or typical conditions and do not belong in a STANDARD providing extremes).

c. The discussions on the need to avoid statements such as "repeated 30 times", noted above, emphasized the point that MIL-STD-210B is not a testing document. Upon preparing these minutes the chairman thought it apropos to suggest that the following be centered on a single page between the foreword and the introduction:*

NOTICE NOTICE NOTICE

> The climatic extremes and associated cycles (or durations) and related meteorological elements presented in this STANDARD describe the natural environment for which equipment should be designed. They are not test conditions or test cycles. Tests to insure compliance with MIL-STD-210B may deviate from these natural conditions only to the extent supported by scientific computations and engineering evidence. Further reference to related mention of testing is provided in Section ______.

d. In sections on absolute humidity, the mixing ratio shall be provided in addition to dew points.

e. For sections on rain intensity, AFCRL will provide nominal values of drop sizes, numbers density, rain drop temperature, and wind speed.

f. It was agreed that there is a need for withstanding precipitation extremes for durations of 1, 12, and 24 hours with a 10 percent risk in expected duration of field exposures of 2, 5, 10, and 25 years. AFCRL agreed to provide such input, including physical characteristics, by extrapolation of National Weather Service studies of such values for the United States. ETAC will provide AFCRL with references to some analogous studies for India.

g. With regard to an urgent need for surface level icing on structures, it was agreed to present whatever ice accretion data are currently available as an expedient, noting its scientific limitations. AFCRL's Design Climatology Branch's (LKI) recent summary of evidence applicable to antenna icing for LORAN D, a worldwide system, will be utilized to the extent possible.

h. A set of tables will be added giving the 1 percent low density and associated temperatures for surface locations up to 15,000 ft (4.6 km) applicable to aircraft takeoff and landing design problems.

*Essential comments during the formal coordination cycle of MIL-STD-210B required the elimination of this statement.

i. It was agreed that dust and sand extremes will be combined to include composition and spectrum of particle sizes and concentrations for three conditions: (1) Natural, (2) natural and normal ground operations, (3) natural and aircraft operations.

j. Navy meteorologists will provide upper air environmental extremes over navigable waters and ports up to an altitude at which they converge with the Extremes for Worldwide Air Environment to 80 km. Extremes will be analogous to those on worldwide air.

k. Values for zero altitude should be included in the naval and worldwide air tables. Land values will be used when they are found near sea level. When not, a more appropriate value will be provided. Linear interpolation between levels will be acceptable.

l. It was also agreed that extremes in the upper air over Antarctica would be excluded from the upper air tables, a modification of the interpretation of the views on page 1, line 13 of the appendix to JCSM-502-69. (A review by the chairman after the meeting revealed that this would raise the low temperature extremes about 8°C only near the 12 km level. However, this increment was indicated as very important in cost of electronic devices on bombs flown at those levels, according to task group engineers).

m. Upper air tables on density extremes at geometric altitudes will provide associated temperature, and vice versa. For worldwide air these will be provided by ETAC and AFCRL (LKI). Affected column headings will be revised accordingly. Temperature in °F as well as °C will be presented if possible.

n. Numerous minor changes, corrections, etc. were made and will be incorporated into the next draft document. Meeting was adjourned with the plan to provide a second draft MIL-STD-210B to participants for individual review and comments before 1 September.

A.9. SINCE JULY 1972 MEETING

Following the July 1972 meeting, formal approval was given by Mr. T. W. Graves (Director, DoD Item Entry Control Office, Directorate for Product and Production Engineering, Office of the Assistant Secretary of Defense—office responsible for MISC-0597) of the task group's decision to eliminate the need to design for extremes in the atmosphere immediately above the Antarctic continent.

In September 1972, the second draft of MIL-STD-210B was completed and distributed to the task group for review. This triggered an Office of the Assistant Secretary of Defense (I & L) meeting of the Departmental Standardization Officers on "Environmental and Design Specifications", 11 and 12 October. Mr. Sissenwine

provided a summary of the background, progress and problems of MIL-STD-210B. Mr. Cormier followed with a presentation of the new climatic extremes, especially those differing from the values in MIL-STD-210A. The second draft was well received.

Many other papers were presented at this meeting, mostly by the engineers concerned with environmental standards. They indicated the importance of a timely completion of this effort, MIL-STD-210B, as most other environmental standards make reference to it and the lack of adequate climatic design criteria leads to problems in testing and qualification of equipment. For example, Dr. John F. Dreher, Air Force Flight Dynamics Laboratory, reviewed a two-year study of 208,000 failures in 175 fighter aircraft, many located in SEA. Of these, 50 percent were environmentally caused and 62 percent of these environmental failures were due to improper consideration of such simple elements of the natural environment as temperature and humidity versus altitude, etc. Average annual failure costs per fighter due to these natural environmental problems exceeded $60,000. If extrapolated to the 4000 aircraft then in SEA, this could amount to $0.25 billion per year.

A major change in one extreme in the proposed MIL-STD-210B was agreed upon at this seminar. The requirement that land equipment operate at a -60°F was relaxed to -50°F. To arrive at this new value, Figures 6 and 7 in AFCRL 70-0158, one of the background documents for MIL-STD-210B, were reviewed. The -50°F has a 50 percent probability during the coldest month in the small cold centers of Siberia. The earlier value, -60°F, has a 20 percent probability in these same areas.

After receiving comments from the task group on the second draft, a third draft was prepared and sent to task group members in March 1973. The major changes incorporated in this draft were:

1. The word "mandatory" no longer appeared anywhere in the document. However, elimination of the word does not appear to change the basic impact of the sentences in which it was contained. This deletion was requested by the AFSC Task Group Representation. They indicated that it was improper to use this word in a DoD Standard since it may become a contractual instrument. The contracting agency, when citing the Standard in contractual documents, indicates that which is mandatory. The OASD (I & L) Office responsible for this MIL-STD-210B project concurred.

2. AFSC also requested that the format of the document conform to that specified in DoD-DSM 4120.3-M, "Standardization Policies, Procedures and Instructions"; this was accomplished.

In May 1973, after all comments on the third draft had been received, the fourth and final draft was prepared. It was forwarded to the Director of Technical Requirements, and Standards, Electronic Systems Division (ESD/DRD) AFSC, USAF for formal DoD coordination. This draft contained an additional cold temperature change. It provided two low temperature operational extremes: -50°F (a 50 percent risk) for equipment whose operation requires the exposure of personnel and -78°F (a 1 percent risk) for other equipments. This change was due to the opposition by various task group members of a -50°F for all equipment as being not cold enough;[90,91] and the realization that equipments not requiring the exposure of personnel for their operation may be required to operate at temperatures colder than temperatures at which human combat is no longer possible.

The fourth draft was sent out for formal coordination by ESD/DRD on 20 June 1973 with a 20 July 1973 suspense date. By early September all essential comments—those that require resolution (as described in DSM4120.3-M)—and suggested comments—those that may be accepted or rejected—had been received. Essential comments were submitted by the Army custodian for MIL-STD-210B,[59] the Navy custodian,[92] and three Air Force System Command Agencies—Headquarters AFSC,[93] Headquarters Space and Missile Systems Organization,[94] and Headquarters Aeronautical Systems Division.[95,96,97] Most of these were minor and easily accommodated in the proposed standard.

90. Askin, D. (1973) 3rd Draft Proposed MIL-STD-210B, Climatic Extremes for Military Equipment, letter of 23 Apr 1973 from Member Task Group (U.S. Army Frankford Arsenal) to AFCRL/LKI (N. Sissenwine).

91. Dreher, J.F. (1973) 3rd Draft, MIL-STD-210B, Feb 73, letter of 19 Apr 1973 from AFFDL/FEE (Wright-Patterson AFB, Ohio) to AFCRL/LKI (N. Sissenwine).

92. McLeod, D.C. (1973) MIL-STD-210 Climatic Extremes for Military Equipment, proposed Revision B (Project No. MISC-0597); comments relating to forewarding of U.S. Navy, Naval Air Engineering Center, Philadelphia, Pa. letter ES-24:HO:vmp of 15 Aug 1973 to Air Force Systems Command, (ESD/DRD).

93. Schultz, P.G. (1973) Proposed MIL-STD-210B, Climatic Extremes for Military Equipment, Standardization Project MISC 0597. Headquarters Air Force Systems Command (SDDP), Andrews AFB, Washington, D.C. letter of 15 Aug 1973 to Air Force Systems Command (ESD/DRD).

94. Kellum, E.G. (1973) Proposed MIL-STD-210B, Climatic Extremes for Military Equipment (Project MISC-0597), U.S. Air Force, Headquarters Space and Missile Systems Organization (DRU), Los Angeles (a letter of 14 Aug 1973 to Air Force Systems Command (ESD/DRD).

95. Dean, R.E. (1973) Coordination of 4th Revision of MIL-STD-210, U.S. Air Force Headquarters Aeronautical Systems Division (ASD/WE), Wright-Patterson AFB, OH, letter of 2 Aug 1973 to Air Force Systems Command (ESD/DRD).

96. Wargo, J.P. (1973) Coordination of 4th Revision of MIL-STD-210, U.S. Air Force, Headquarters Aeronautical Systems Division (ASD/WE), Wright-Patterson AFB, OH, letter of 10 Aug 1973 to Air Force Systems Command (ESD/DRD).

97. Gebhard, J.B. (1973) Coordination of 4th Revision of MIL-STD-210, U.S. Air Force, Headquarters Aeronautical Systems Division (ASD/WE), Wright-Patterson AFB, OH, letter of 21 Aug 1973 to Air Force Systems Command (ESD/DRD).

However, there were two main essential comments. These were objections with the inclusion of verbiage setting forth provisions for exceptions and the justification thereof from the design criteria, and with the operational low temperature extreme. All the above agencies indicated that matters related to exceptions and justification are not within the purview of a military standard; they belong in regulations or implementation documents of each Service. Accordingly, verbiage related to exceptions and justification thereof was removed from proposed MIL-STD-210B.

With regard to the operational low temperature extreme, essential comments indicated that the design criteria for equipment not requiring personnel exposure for operation, -78°F was far too cold; and that the criteria for equipment requiring the exposure of personnel for operation, -50°F, was too warm. Furthermore, the problems associated with defining equipment as to requiring or not requiring the exposure of personnel for operation were pointedly exposed. It thus appeared that specifying two low temperature design criteria for operation had opened a Pandora's box. Accordingly, a return to the low temperature design criteria that appeared in the first and second drafts of proposed MIL-STD-210B and which was approved by the Project MISC-1597 Task Group (-60°F, a 20 percent extreme) was proposed by Cormier[98] to eliminate this newly created problem and also to strike a compromise insofar as the actual value of the criteria. This proposal was acceptable to the interested parties and this change was incorporated in the proposed standard.

The resolution of all essential comments took place by 15 December 1973. Thus on this date, MIL-STD-210B became fact and was submitted for printing and distribution.

98. Cormier, R.V. (1973) Replies to Army, Navy, and Air Force Essential Comments on 4th Draft MIL-STD-210B, Memorandum for Record dated 27 Sep 1973, Air Force Cambridge Research Laboratories (LKI), Bedford, MA.

☆ U.S. GOVERNMENT PRINTING OFFICE: 1974--704-297--80